Evaluating the impact of land use and policy on water quality in an agricultural catchment: The Leet Water, south-east Scotland.

Penelope Elizabeth Widdison

PhD Thesis,

University of Durham 2005

Declaration of Copyright

I confirm that no part of the material presented in this thesis has previously been submitted by me or any other person for a degree in this or any other university. In all cases, where it is relevant, material from the work of others has been acknowledged.

The copyright of this thesis rests with the author. No quotation from it should be published without prior written consent and information derived from it should be acknowledged.

Signed: P. E. Widdison

Date: 14/11/05

Evaluating the impact of land use and policy on water quality in an agricultural catchment: The Leet Water, south-east Scotland.

Penelope Elizabeth Widdison

PhD Thesis, University of Durham 2005

Abstract

This is an interdisciplinary study combining research techniques from the natural and social sciences, to evaluate the impact of EU policies and land use change scenarios for assessing water quality in an agricultural catchment. The study focuses on the Leet Water catchment, a left-bank tributary of the River Tweed, Berwickshire, south-east Scotland. The Leet Water and its subcatchment the Lambden Burn cover an area of approximately 114km^2 within the Lothian and Borders Nitrate Vulnerable Zone (designated in 2002).

In the Leet Water catchment, spot measurements of nitrate (NO^3-N) from 1977 to 1998 found the 11.3 mg/l (EU permitted maximum) was often exceeded. Further spot monitoring from October 2002 to August 2004 found 12 instances where the 11.3 mg/l permitted maximum was exceeded with all streams in the catchment experiencing high levels of nitrate over the winter periods. Interviews with local farmers, advisors, and the regulators found this to be the result of a complex set of circumstances including long-term Common Agricultural Policy subsidies and the farmers' drive for increased profitability without due regard for the environmental consequences. Land management practices such as under-draining of fields, overuse of fertiliser and allowing livestock access to water-courses has exacerbated the problem.

The study demonstrates the potential of multispectral airborne remote sensed data for mapping agricultural land cover at the field scale, including the ability to distinguish winter and spring-sown cereal crops. Pollution impacts were modelled using a modified export coefficient approach by integrating land cover with available chemical and fertiliser practice data sets. Results of modelling scenarios of simple land use changes found that reducing fertiliser use by 10% can reduce the number of fields in the very high risk group from 191 to 16 This equates to reducing the high risk area from ~3255 ha (29% of the catchment) to ~428 ha (3.3 % of the catchment). This method of water quality modelling provides a means of integrating field research on water quality with the results of socio-economic surveys.

The research found the principal causes of the failure of EU policy to address the problems are both socio-economic and institutional barriers, in particular the way in which information is presented to the farming community. Case studies of both large and small farms reveal that agri-environment measures such as the 'points' based Rural Stewardship Scheme (RSS) can attract substantial funding. However, these schemes are of most benefit to large farms where significant land use changes that accrue points can be made. Smaller farms find it difficult to suggest changes that will accrue these 'points' for a successful application. Furthermore, farmers believe recent changes e.g. the Land Management Contract implemented by The Scottish Executive may include a range of funding opportunities for improving land management practices but these are not well presented. There are gaps in the knowledge transfer process in relation to water quality issues between Government and land users. This research suggests that independent facilitators (advisors) such as those used in the Australian Landcare approach should be introduced in the UK to help address this problem.

Key words: Water quality, nitrate pollution, remote sensing, Water Framework Directive, Nitrate Vulnerable Zones, Common Agricultural Policy, Agri-environment schemes.

Acknowledgments

Numerous people have assisted me throughout my PhD. I cannot mention all by name, but my appreciation and thanks goes to every one of you. Firstly I should like to acknowledge support from the following institutions. Funding was made possible through the ESRC/NERC Interdisciplinary Research Studentship scheme, award number R42200134149. Aerial photography and remote sensed imagery were acquired through the NERC ARSF, award number 02/06. The Scottish Environment Protection Agency provided water quality data sets and, in particular I would like to thank Allan Virtue and Will Dryburgh at the SEPA office Galashiels, for their help. I am also grateful to the University of Durham for their investment in the project.

Many, many thanks go to Professor Tim Burt, Professor Ray Hudson and Dr Danny Donoghue, who supervised this project. Their constant encouragement and advice throughout the study period and scrutiny of draft chapters kept me going and completion of the thesis would not have been possible without them.

I would also like to thank everyone who gave up their time for interviews and patiently answered all my questions. These include SEERAD, SEPA, SNH, SAC, FWAG, SLF, Tweed Forum, and SNFU. A special mention goes to all the farmers in the Leet catchment that I met and I am particularly grateful for their contribution to the thesis.

The lab technicians and IT support staff at Durham deserve a special mention: Frank and Eddy for their humour in braving the nettles and vicious vegetation when helping me with water monitoring; Terry, David and Ant for keeping the computers working, Alison and Neil for keeping me on the straight and narrow with lab protocol and, the department secretaries, who were always supportive and understanding.

My friends in the Open University Geological Society have been a constant source of moral support, Dave, Helen, Lorraine, Lynda, Pam and Jim – thank you for being at the end of a phone when I needed you. Friends in the post-grad community, too many to mention individually, but especially Rob, Alona, Pete, Sarah W, Matt and Elizabeth, I will always remember you. Long may we continue to drink and eat cake together!

Lastly I must thank my husband, Robin, who has provided more support and encouragement than I can ever repay, I promise there will be no more working on Sundays.

Table of Contents

List of Figures

List of Tables:

Chapter One:
Nitrate in agricultural catchments

1.1 Introduction

This study focuses on the key proposition that the freshwater pollutant nitrate can only be fully understood by integrating an understanding of the physical processes of nutrient storage and flux in the environment with an appreciation of the socio-economic and behavioural context that results in enriched levels of these elements in the environment in the first place.

This research differs from traditional water quality modelling that focuses on predicting the consequences of land use change in agricultural catchments. Here, an integrated natural and social science approach is used to determine how stakeholders' knowledge, understanding and decision making about the impacts of European Union (EU) legislation can be incorporated into a water quality model. In this way, the impact of changes in policy in land management practices and water quality can be evaluated. Sophisticated models of pollution transfer already exist, these are introduced in chapters 8, 9, and 10 of the classic text Nitrate Processes, Patterns and Management (Armstrong and Burt, 1993; Burt and Trudgill, 1993; Johnes and Burt, 1993). However, these have rarely been applied to real landscapes, which are the product of complex interactions of physical, biological and socio-economic factors.

Controlling agricultural water pollution is difficult because its sources are often diffuse and difficult to identify. It depends not only on hydrology and drainage basin characteristics such as rainfall-runoff patterns, topography, and soil type characteristics, but also on farmers' land use and crop choices, production techniques, and fertiliser uses. Farmers' decisions in turn are affected by market prices for inputs and outputs as well as by governmental price support levels.

1.2 The nitrate issue

1.2.1 The scale of the problem

Nitrogen is vital for plant growth. In terms of agricultural output, nitrogen enables the farmer to achieve higher crop yields. Recycling of organic matter, fixation by leguminous plants and fixation from the atmosphere are 'natural' methods of obtaining nitrogen but all are limited in the quantities of nitrogen produced. To maximise crop yields, nitrogen can be supplemented by artificial fertilisers.

In the post-war period (from 1945) agriculture in the developed countries of the world was put under pressure to produce higher yields from cereal crops. New varieties of higher yielding seeds were introduced and poorer soils were brought into agricultural production. As part of this boost for agricultural production, artificial fertilisers, most based on inorganic nitrogen, were developed and used in greater amounts to help productivity (O'Riordan and Bentham, 1993). In the UK alone, from the mid 1940s to mid 1980s, the use of nitrogen fertilisers rose by 900% and phosphorus by 500% (Parkinson, 1993). The United Nations Food and Agriculture Organisation (UN-FAO) reported that by the late 1980s the application of nitrogenous fertilisers in the UK averaged 350 N kg/ha. (O'Riordan & Bentham, 1993).

However, by 1985 there was a growing concern voiced by environmental groups about the health risks and water pollution associated with the use of large amounts of nitrogen fertilisers. As a result, several studies were undertaken to assess the extent of the nitrate loss from agricultural land in various parts of the UK. Armstrong and Burt (1993) describe three of these studies carried out at Brimstone Farm in Oxfordshire, Cockle Park in Northumberland and North Wyke in Devon. The results indicate that as much as 30 - 50% of the nitrogen from the fertiliser applied may be lost to the atmosphere through denitrification, and up to 30% through leaching.

It is now widely accepted that agriculture makes significant contributions to water pollution, mainly by leaching but also by surface runoff. This is one cause of the environmental and health concerns particularly with the quality of drinking water sources.

1.2.2 Environmental issues

Wherever the nutrients nitrogen (N) and phosphate (P) enter surface water-courses in excessive amounts there are environmental concerns. Nitrate and phosphate not only help crops to grow, but also encourage the growth of aquatic plants. Reed beds and other marginal plants may be attractive on a small scale, but when these and, particularly, underwater plant growth become excessive, this can cause a narrowing of waterways, and become a nuisance to recreational users of rivers and lakes. Eutrophication (a group of effects caused by nutrient enrichment of water bodies) produces a breakdown in the aquatic ecosystem. When algal blooms flourish, they cut out light to the subsurface and when they die, decomposition uses the oxygen supply needed by other species. Some of the algae are toxic to fish, whilst others, for example cyanobacterial species, are toxic to mammals including domestic pets (Addiscott, 1996).

It is now widely acknowledged that agriculture is the main source of N pollution in surface waters and groundwater in rural areas of Western Europe and USA (Burt and Trudgill, 1993; Power *et al.*, 2001; Royal Society, 1983). The UK House of Lords' report *Nitrate in Water* (House of Lords, 1989) commented on the conflicts which can arise when the use of land for farming comes into conflict with the use of land for water supply. Concern initially focused on alleged links between high nitrate concentrations in drinking water and two health problems in humans: the 'blue-baby' syndrome *methaemoglobinaemia* and gastric cancer. Now, there are also concerns for the environmental degradation of aquatic ecosystems as noted above.

1.2.3 Water quality in the Tweed Basin

The basic determinants of water quality are – pH, temperature, suspended solids, dissolved oxygen, biochemical oxygen demand (BOD), nitrogen species (nitrate, ammonia, and nitrite), phosphate species, chloride and silica. This research will focus on levels of Nitrate (NO_3-N) in the Leet Water and Lambden Burn. These two basins together form a sub-catchment of approximately 113 km^2 within the Tweed river basin, situated in south east Scotland (figure 1.1 below), at the confluence of the Leet and Tweed near the town of Coldstream. The area is largely rural, of low population and mainly agricultural. The Leet and Lambden Burn (figures 1.2 and 1.3 below) are small and relatively slow flowing, in contrast to the faster flowing, upland streams in the Tweed Basin. These water-courses have been significantly altered in the past, in particular during land drainage schemes of the 1970s; this was accompanied by major intensification of agricultural production, a process that has continued through to today. These changes have been the main cause of the problems of poor water quality in the catchment.

Figure 1.1 The Leet Water catchment drainage pattern

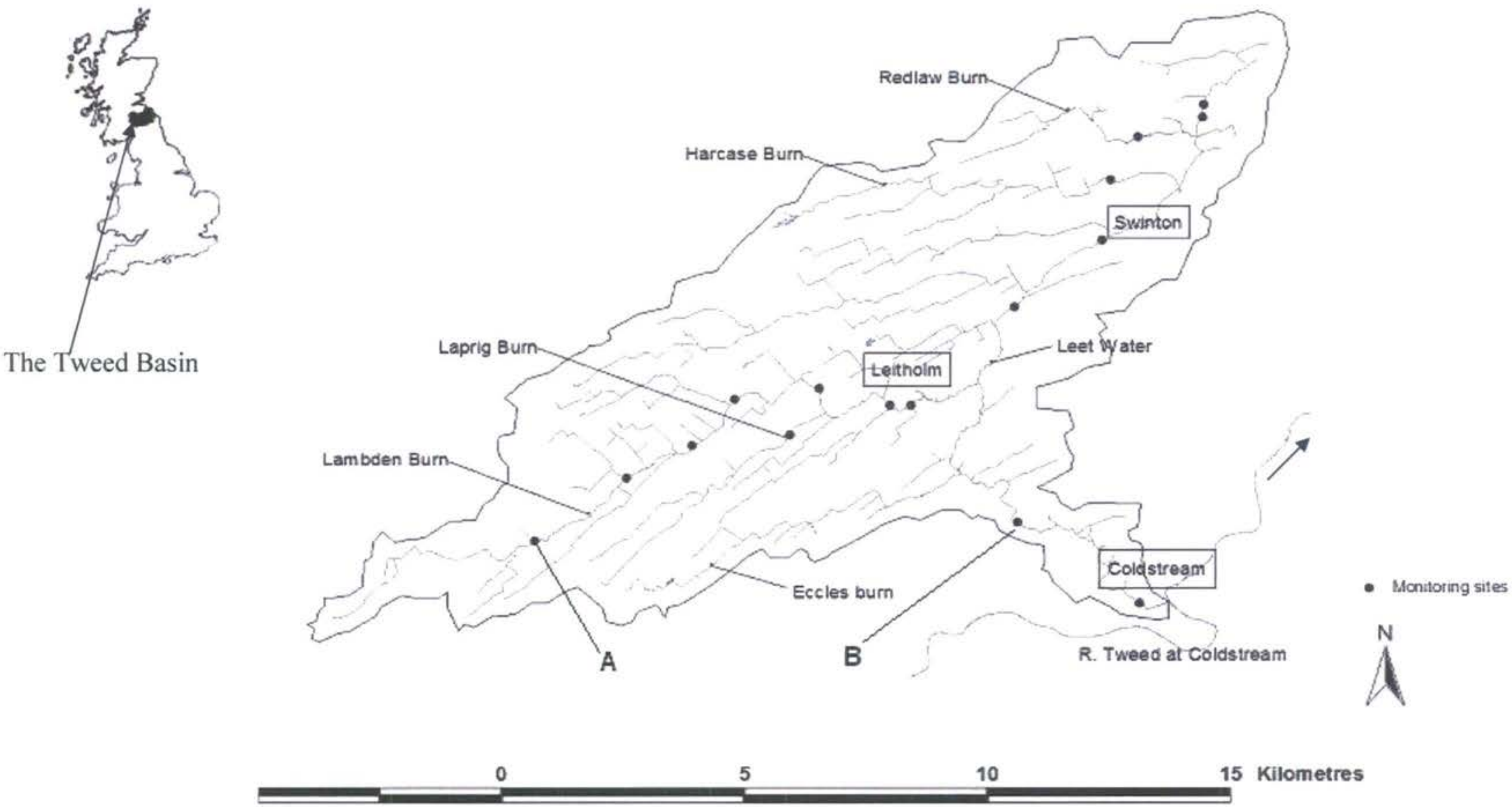


Figure 1.2 Lambden Burn below Hume Hall.

(location A on map above)

Figure 1.3 Leet Water at Charterpath Bridge

(location B on map above)

Water quality monitoring carried out by the public regulator in this area, the Scottish Environment Protection Agency (SEPA) has found high concentrations of nitrate in the relatively small water-courses draining low-lying drainage basins in eastern regions of the Tweed River Basin, where the land use is predominantly arable farming (Robson and Neal, 1997). Long-term historical water quality data are available from 1960 for nitrate at Charterpath Bridge (figure 1.3 above) and from the mid 1980s for phosphate (figure 1.5 below).

Figure 1.4, illustrates spot measurements from Charterpath Bridge collected between 1960 and 1998 indicate a general rising trend of nitrate concentration throughout the period, and Table 1.1 (extracted from the time series data) indicate that nitrate has often been above the EU Drinking Water Directive permitted level (11.3 NO_3-N mg/l), and that exceedence events have increased in frequency during the 1990s. Further data from a range of other sites in the catchment area are also available to the research and the trends of these are described in Chapter Three.

In addition to high concentrations of nitrate, phosphate levels (figure 1.5 below) have been found to range from <0.1 to 1 mg/l. The UK criterion for running freshwaters subject to eutrophication by P is 0.1mg/l. Therefore the Leet Water and the Lambden Burn have been classed as eutrophic (IOH Report 128, 1996).

Figure 1.4 NO_3-N mg/l spot measurements – Charterpath Bridge 1960 – 1998 [1]

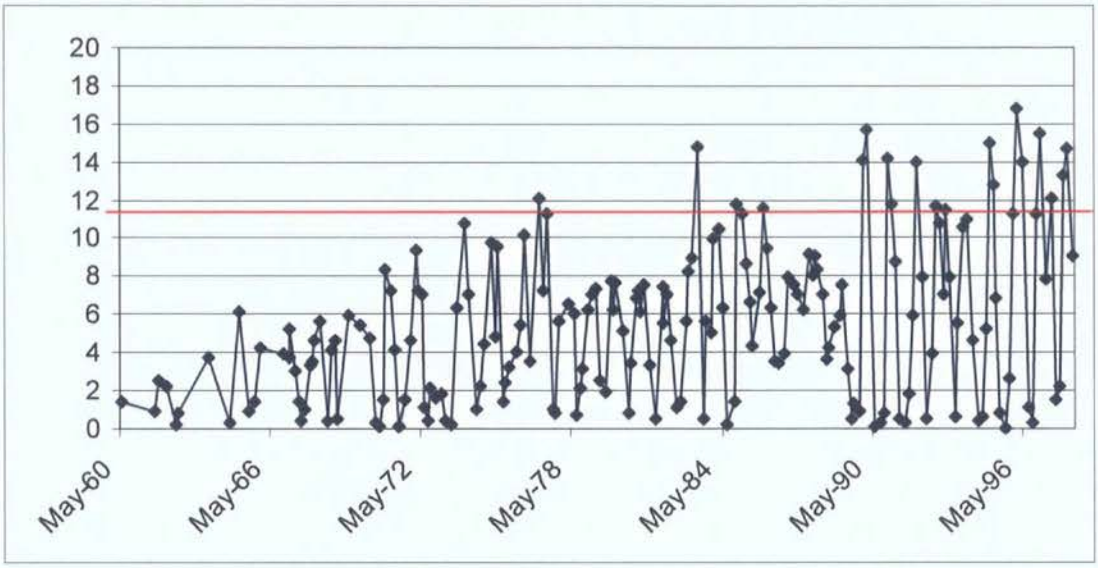
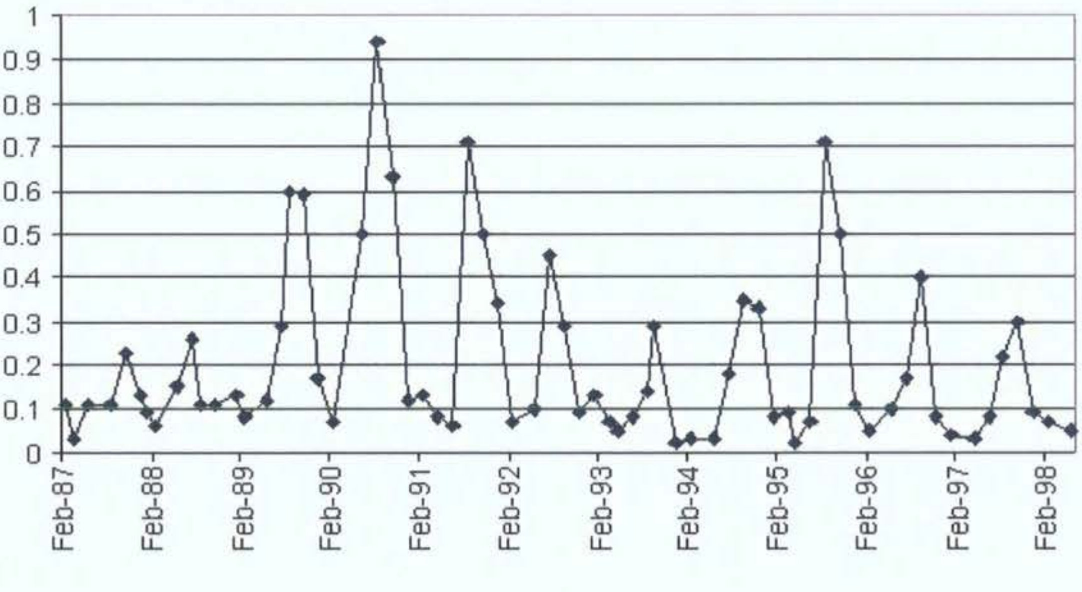


Figure 1.5 Phosphate mg/l spot measurements – Charterpath Bridge 1987 - 1998



[1] Where a red line is shown on all NO_3-N graphs this indicates the 11.3 mg/l permitted maximum

Table 1.1 Selected NO3-N data Charterpath Bridge:

NO_3-N above the 11.3 mg/l permitted maximum 1960 - 1998

Date	NO_3-N mg/l
Jan 77	12.1
May 77	11.3
May 83	14.8
Nov 84	11.8
Dec 85	11.6
Dec 89	14.1
Feb 90	15.7
Dec 90	14.2
Feb 91	11.8
Feb 92	14.0
Nov 92	11.7
Apr 93	11.5
Jan 95	15.0
Mar 95	12.8
Dec 95	11.3
Feb 96	16.8
May 96	14.0
Nov 96	11.3
Jan 97	15.5
Jun 97	12.1
Dec 97	13.3
Feb 98	14.7

1.3 A river basin approach

Sophisticated models of pollution transfer already exist (Burt *et al.*, 1993). However, these have rarely been applied to real landscapes, which are the product of complex interactions of physical, biological and socio-economic factors. The application of policies (such as the EU Nitrate and the Water Framework Directives) does not take into account local and regional factors and this has been shown to have serious consequences for policy effectiveness (Hudson, 1999). Similarly the lack of attention to landscape variability has limited the success of the Nitrate Directive in many European regions. The spatial variation in socio-natural relationships can be of critical importance in determining the effectiveness of policy implementation.

Given that diffuse pollution loading may be mitigated through landscape structures such as riparian buffer zones, it is important to understand how policies may affect farm management practices and thereby water quality (Burt and Johnes, 1997; Burt *et al.*, 1999). Although farmers react to policies and incentives according to economic criteria, they may also react according to their production type, the structure of their farm territory and their place-specific, local and tacit knowledges (Hudson, 1999; Lowe *et al.*, 1997). This is an area where further research is required.

1.4 Aims and objectives of the thesis

The overall aim of this project is to develop a user–friendly land use management-modelling tool with visualisation capabilities. The model will predict the impacts of land use changes and the consequences of landscape change on water quality in river basins at the field scale. This will be accomplished by addressing a number of objectives:

- To identify and evaluate relevant EU policies for water quality and river basin management;

- To ascertain the views of members of the farming community and other stakeholders to assess the possible impacts of existing policies;

- To assess the potential of multispectral remote sensed data for mapping precise land cover at the field scale including the ability to distinguish winter and spring sown cereal crops;

- To develop a geographical information system (GIS) of land cover structures and patterns as a tool to allow pollution impacts to be modelled using the best available data sets;

- To model scenarios of landscape change and thereby identify and evaluate the sustainability of landscape structures that regulate nutrient flux under different farming systems.

1.5 Thesis structure

Chapter One presented an overview of the nitrate problem and its relevance to the study area, the Leet Water catchment; it has identified a gap in existing research from which are derived the aims and objectives of the project.

Chapter Two reviews the literature of previous research in terms of:

- The impact of agriculture on diffuse pollution;
- Existing nutrient and water quality models;
- The use of remote sensing in land use classification;
- Policy instruments and national guidelines for improving water quality;
- Existing examples of community approaches to river basin management;
- Stakeholder perceptions and public participation for environmental (water quality/river basin) management and decision making processes.

The characteristics of the study area and site selection criteria are described in Chapter Three. Chapter Four addresses the social and economic aspects of the research, presenting the methodology and results for evaluating the impact of policy on water quality. This includes stakeholders' surveys and in-depth interviews. Chapter Five examines the natural science methodology developed to produce a precision land cover map at the field scale. The results are used to compare the techniques of aerial photography, multispectral remote sensed data and manual data collection.

In Chapter Six, the results of water quality monitoring are presented and applied to two tired and tested existing models; 1) the export coefficient approach (Johnes, 1996; Johnes and Heathwaite, 1997) and 2) the Integrated Nitrogen Catchment (INCA) model (Whitehead *et al.*, 1998a; Whitehead *et al.*, 1998b). The models are used to evaluate the prediction of changes in water quality from a range of land use change scenarios.

Chapter Seven discusses the results of scenario modelling in the context of EU policy implications and the availability of funding to implement practical agri-environment schemes. Case studies highlight the extent to which the farmers in the Leet Water catchment believe they can modify their day-to-day farm management decisions to comply with legislative requirements. Chapter Eight summarises the results of the research and considers the prospects both for further research and for changes in water quality in the light of ongoing changes in policy.

Chapter Two:

Nitrate pollution, modelling techniques and legislation: a review of theoretical and empirical studies

2.1 Introduction

This chapter discusses relevant theoretical and empirical studies of nitrate pollution in agricultural areas and the legislation aimed at reducing its impact on water quality. Nitrate pollution from diffuse agricultural sources has been the focus of much research. For example, studies have tended to concentrate on the problem of poor water quality from a natural scientific standpoint. An important research direction has been to develop physical models that predict and simulate the transport of nitrate from land to water courses. From a socio-political stance, research has focused on legislation and the outcome of measures designed to reduce the impacts of agricultural pollution from diffuse and point sources. Furthermore, most research has focused on the water quality problem using a 'top-down' approach and as a series of separate issues rather than an integrated research programme which brings together natural and social science methodologies and which takes into account end-user preferences and abilities that is a 'bottom-up' approach.

In this chapter nitrate flux is discussed with methods of simulating and predicting the movement of nitrate from land to water. The use of remotely sensed data in land use classification is then examined. Finally, the policy instruments aimed at reducing the impacts of diffuse water pollution are described.

2.2 The impact of agriculture on diffuse water pollution – the nature and extent of the problem

2.2.1 Nitrate pathways

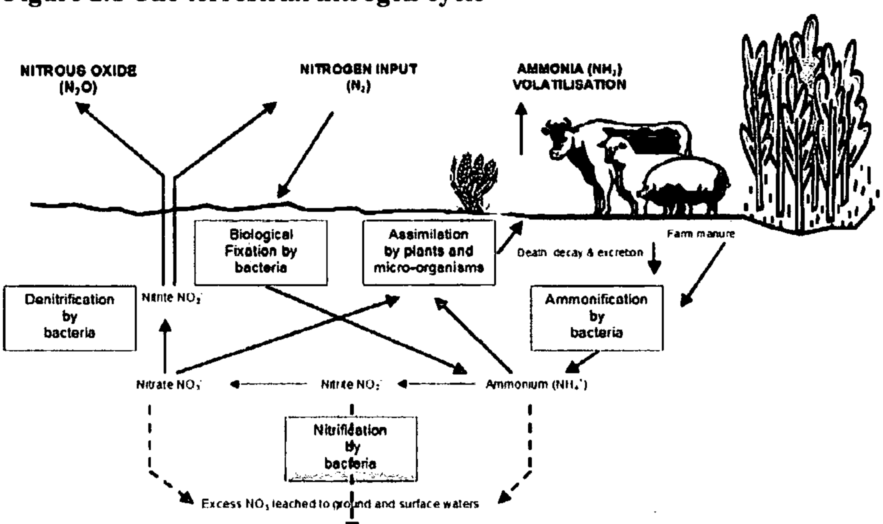
The temporal variation of observed instream nitrate concentrations is the product of a complex set of factors. It involves nitrogen inputs, losses, transformations and transportation.

Nitrogen is essential to plant growth and comprises nearly 79% of the Earth's atmosphere in the form of N_2 gas. In order for nitrogen to be used for plant growth it must be "fixed" in the form of ammonium (NH_4) or nitrate (NO_3). In the terrestrial nitrogen cycle, microbes break down organic matter to produce much of the available nitrogen in soils. Nitrate is soluble in water; therefore it is vulnerable to being leached out of the soil by percolating rainfall or irrigation water. Generally, the movement of nitrogen can be described in three ways:

- Upward, crop uptake and gaseous loss;
- Downward, as leaching to groundwater;
- Lateral, via surface and subsurface flow to surface waters.

The terrestrial nitrogen cycle is shown in Figure 2.1 below.

Figure 2.1 The terrestrial nitrogen cycle



2.2.2 *Nitrate: a global problem*

In pristine river systems, the average nitrate concentration is about 0.1 mg per litre as nitrogen (mg/l NO_3-N) (WHO, 2002). However, in Western Europe, high atmospheric nitrogen deposition results in nitrogen levels of relatively unpolluted rivers that range from 0.1 to 0.5 mg/l (*ibid*). High rates of nitrogen input to rivers and coastal waters is not confined to Europe. In an average year the Mississippi River discharges 1.57 million metric tons of nitrogen into the Gulf of Mexico (United States Geological Survey, 2000). About 7 million metric tons of nitrogen in commercial fertilisers are applied annually in the basin leading to nitrate concentrations in agricultural drains of 20 to 40 mg/l or more (*ibid*). In the USA in 1998, more than one third of all rivers, lakes (excluding the Great Lakes) and estuaries did not support the uses for which they were designated under the Clean Water Act (Ribaudo, 2001). Furthermore, Table 2.1 illustrates the typical amount of N inputs to rivers and coasts in areas of America, Africa and Asia (Norse, 2003).

Table 2.1 Nitrogen inputs to rivers and coastal waters

River	N Inputs to rivers kg year $^{-1}$	N exports to coastal waters kg year $^{-1}$
Mississippi	7489	597
Amazon	3034	692
Nile	3601	268
Zaire	3427	632
Zambezi	3175	330
Rhine	13941	2795
Po	9060	1840
Ganges	9366	1269
Chang Jiang	11823	2237
Juang He	5159	214

Source: (Norse, 2003)

Studies in Asia have demonstrated the link between increased use of fertilisers and increased incidence of algal blooms. In some Chinese provinces, fertiliser application is greater than 400kg/ha. This is usually applied as a single application, and with crop utilisation efficiency as little as 30-40%, a high proportion is lost to rivers, lakes and coastal waters (Norse, 2003). The environmental impact at the regional level has led to a rise in the incidence of 'red tides' (algal blooms). For example in China, during the 1960s, less than 10 red tides per year were recorded, but in the late 1990s over 300 per year were being recorded (*ibid*).

The popular misconception that the nitrate problem is caused by farmers applying too much nitrate fertiliser is too simplistic. Nevertheless, there is now little doubt that the high concentrations of nitrate in fresh waters noted in recent years have mainly resulted from runoff from agricultural land. Furthermore, the progressive intensification of agricultural practices with increasing reliance on the use of nitrogenous fertiliser, has contributed significantly to this problem. Since 1945, agriculture in the industrialised world has become much more intensive. For example:

- Fields are ploughed more frequently;
- More land is devoted to arable crops, most of which demand large amounts of fertiliser;
- Grassland too receives large applications of fertiliser to ensure a high quality silage for winter feed;
- Stocking densities in general are higher leading to increased inputs of manure on grassland and problems of disposal of stored slurry;
- Cattle often have direct access to water courses resulting in soil and bank erosion and direct contamination from animal waste;
- Many low-lying fields are now underdrained, encouraging more productive use of the land and speeding the transport of leached nitrate to surface water courses.

It is true that lowland rivers close to urban areas receive larger quantities of nitrogen from sewage effluent, but budgetting studies confirm that agriculture is the main source of nitrate in river water (Burt and Johnes, 1997; Norse, 2003).

2.2.3 Landscape structures to mitigate diffuse water pollution

Riparian Buffer Zones (RBZs), the permanently vegetated areas located between pollutant source and water bodies, are known to improve water quality (Burt, 1993; Cooper *et al.*, 1997; Cooper *et al.*, 1987; Narumalani *et al.*, 1997). Movement of water and nutrients is usually from the land to the aquatic system, although over-bank flooding or river water seeping into the channel bank may reverse the normal direction of flow. Where there is little or no ground cover, water and nutrients move quickly into the water-course, polluting it. The land and its vegetation adjacent to the water-course can act as a sink or filter to remove quantities of nitrate (and other toxic substances) and therefore improve water quality. Groundwater may be cleansed of nitrate and acidity due to a combination of denitrification, bio-storage and changes in soil composition. Suspended particulates in surface runoff and overland flows may become trapped in vegetation, and after a flood event, the floodwaters that flowed out onto the RBZ leave behind fine-grained sediments to which nutrients and toxic materials may be bound. RBZs provide other benefits too. Trees and shrubs provide food and cover for wildlife and help lower water temperatures by shading the water. Annual leaf-fall produces large quantities of organic material used as food by smaller organisms. The root systems of trees and other vegetation help to bind the soil; this in turn helps to maintain the stability of the riverbank and reduce the risk of erosion.

In assessing the effectiveness of a Riparian Buffer Zone certain internal and external factors have to be considered. Watershed area, gradient, stream channel morphology, soil mineralogy and texture, bedrock type and depth, and climate are all limiting external factors (Correll, 1997). Correll goes on to state that buffer width and type of vegetation, water-logging and organic content of soil, hydraulic conductivity, soil nutrient content and geochemistry are the internal limiting factors. He concludes: "For effective removal of nitrate and acidity, groundwater must move through the RBZ at slow speed and a shallow enough depth to within the rooting zone of riparian vegetation. The vegetation in the RBZ must provide enough friction to surface flows to improve the efficiency of particulate trapping".

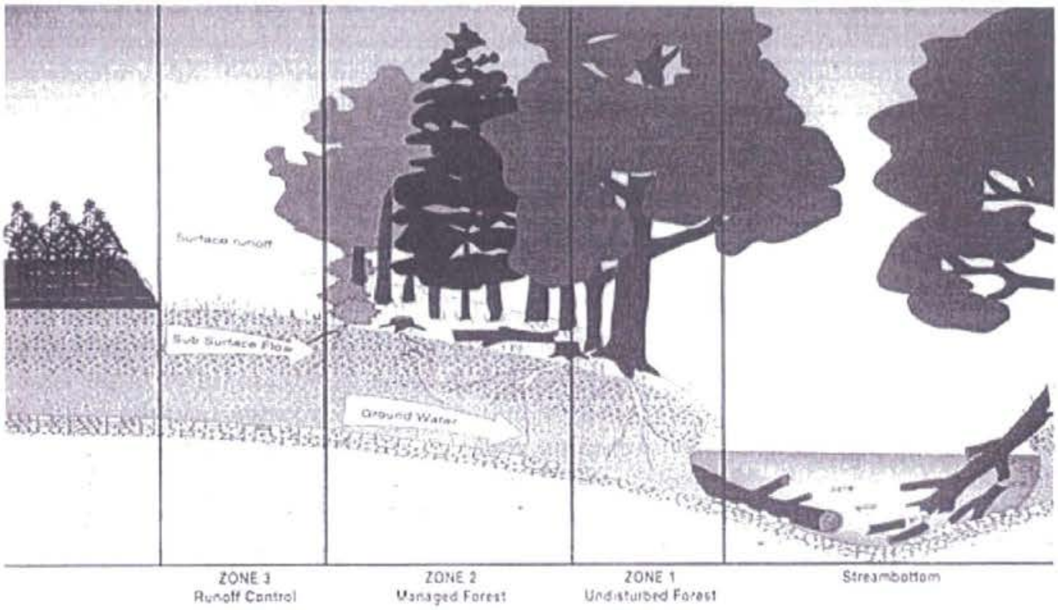
2.2.4 *Nitrogen removal by riparian buffers*

Surface vegetation and in particular the presence of trees has traditionally been considered the most important factor in nitrate absorption. However, some studies have argued that the mere presence of saturated soils and a carbon-rich sediment can optimise the rate at which denitrification occurs irrespective of vegetation cover (Burt *et al.*, 1999). Nitrate concentration in shallow groundwater flowing through a RBZ can be reduced by as much as 90% (Gilliam *et al.*, 1997). They question the length of time a riparian buffer may be effective, but where riparian buffers are receiving continuous inputs of organic carbon from surface vegetation they are likely to be effective and act as a sink for nitrate. However, when a plant dies, it becomes a potential source of pollution and add to the problem (Dillaha and Inamdar, 1997; Riddell-Black *et al.*, 1997). A question is also raised about which type of vegetation in a buffer zone is more effective. Some scientists say trees with their deeper rooting systems increase both plant uptake and carbon supply required for denitrification, while others argue that grasslands tend to have more organic matter deeper in the soil profile (Gilliam *et al.*, 1997).

2.2.5 *Riparian forest buffers*

The use of established forestry (30 to 75 years old) as a RBZ has been described in (Haycock et al., 1997), and more recent work on restored woodland (for example, Vellidis et al., (2003) has shown that after only eight years, restored areas can retain 59% nitrate. Lowrance (1997), argues that forestry is particularly important on small streams and, working with the US Department of Agriculture Forest Service, he has developed a three-zone land management specification (figure 2.2. below).

Figure 2.2 Three Zoned Riparian Buffer Zone System (Lowrance *et al* 1997)



Source Haycock *et al* p.38

Zone 1 is permanent woody vegetation adjacent to the stream bank; in Zone 2, managed forest occupies the adjacent upslope strip; and Zone 3 is a herbaceous filter strip upslope from Zone 2. The main purpose of Zone 3 is to remove sediment from surface runoff. Zone 2 acts as a block to sediment transport, and plant roots take up nutrients and chemicals flowing from the upland areas. Zone 1 performs similar functions to Zone 2, but also provides bank stability and a favourable habitat for aquatic organisms by its moderating influence on water temperature.

Riddell-Black *et al* (1997), argue that by using forestry not only for water quality protection but also as a sustainable fuel and wood source, farmers could be encouraged to use riparian forestry buffer zones. Plantations could be located beside vulnerable water-courses. This would have several advantages: livestock would be prevented from gaining direct access to the water side, therefore stabilising the river bank against erosion and pollution; pesticide runoff and spray drift would be intercepted by the trees; but most importantly, farmers could gain an income from selling timber (in Zone 2) from land that is dedicated to water quality protection.

2.2.6 *Grass buffers*

Research by the University of Kentucky during the late 1970s and later work by Dillaha and Inamdar (1997) have shown the effectiveness of grassland buffers in the US. In hilly areas, grass buffers were not very effective for sediment trapping - they soon became clogged up with sediment - but were beneficial in providing cover to the stream bank where localised channel and gully erosion occurred. In flatter areas the grass buffers were most effective as long as the vegetation was not submerged (*ibid*). However, there are several problems associated with using grass buffer zones. Grass buffers need considerable maintenance if they are to remain effective. Sediment tends to build up within the first one metre of the buffer, producing a berm. These have to be ploughed out periodically and the buffer re-seeded. Herbaceous buffers need to be mowed two to three times a year to maintain the potential of vegetation density at ground level for sediment retention. Herbicides sprayed in adjacent fields can damage the buffer vegetation. Livestock must be excluded from buffers at all times to prevent trampling of vegetation and the addition of nutrients from animal excreta.

2.2.7 *Impact of buffer zones on farming practices*

Although there are clear environmental benefits to the establishment of RBZs, they have been criticised by some farmers as being costly in that they remove good land from production and require extra time to maintain them (Cooper *et al.*, 1997). The Morley Research Centre, a 370 ha demonstration farm in Norfolk (UK), has investigated the practical use of 6-metre buffer zones around drainage ditches and their effects on farming practices (Cook, 1997). The Research Centre found many environmental advantages to the buffer strip: the water-courses were protected from nitrogen and pesticide residues; the bio-diversity of field margins increased; the movement of toxic products in surrounding habitats was reduced; the un-cropped strips allowed winter hedging to be carried out without crop loss. However, they also found several disadvantages: there was less efficiency in small fields; buffer zones had to be cultivated after the adjacent crop was established which led to damage and loss of potential in an area adjacent to the buffer. The restrictions on the use of chemicals within 6m of the water-courses resulted in a revisit to unsprayed areas to use an acceptable substitute incurring extra labour costs. Cook states that in financial terms net farm income was reduced by about 6% (*ibid*).

2.2.8 *Constructed wetlands, retention ponds and reed beds*

Since the mid 1990s there has been much research interest in the effectiveness of constructed wetlands (retention ponds) and reed beds as a means of removing pollutants before waters reach the receiving water-courses (Braskerud, 2002; Geary and Moore, 1999; Ingersoll and Baker, 1998; Koskiaho *et al.*, 2003; Platzer, 1999; Serra *et al.*, 2004; Silvan *et al.*, 2003). For example, from 1990 to 1997, 65 pilot or full-scale wetlands had been constructed in the US to treat livestock wastewater. Since then the Australian Dairy Research & Development Corporation has funded the construction of wetlands in New South Wales.

Under optimum conditions, Geary and Moore (1999) found that removal of organic N in Australian wetlands was as much as 43% ; Ingersoll and Baker (1998) working in Florida (USA) found removal efficiencies to vary from 8% to > 95%. The study by (Koskiaho *et al.*, 2003) in Finland found constructed wetlands with long water residence times performed better than wetlands with shorter residence times; the best performance, retaining annually about 2 300 kg of Total Nitrogen per hectare.

Construction or restoration of small ponds and wetlands are now common measures for reduction of nitrogen flux to coastal waters in Denmark, Finland and Sweden. Although the specific design, shape and size will vary from site to site according to particular requirements, most have the same features. Figures 2.3 and 2.4 below illustrate the four main features required to treat incoming polluted waters as they move through the system to the outlet and receiving watercourse:

- Sedimentation / settlement pond;
- Constructed wetland filter;
- Overflow zone;
- Final sedimentation pond / outlet basin.

Figure 2.3 Design features of a constructed wetland

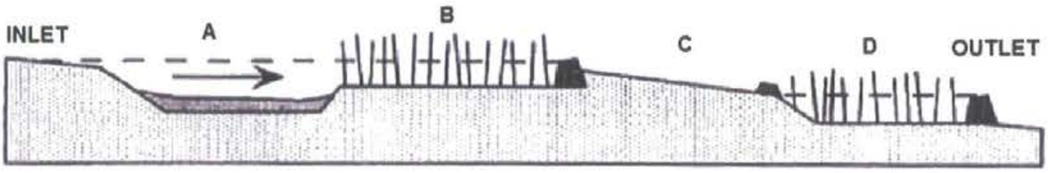
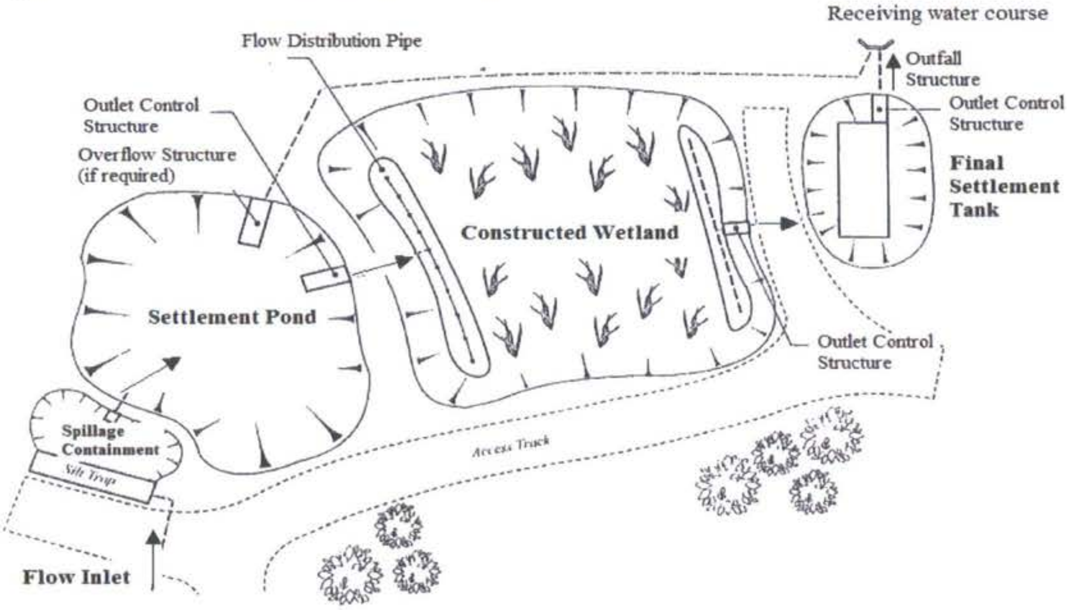


Figure 2.4 Plan view of a constructed wetland



After (Braskerud, 2002; Shutes, 2001)

Constructed wetlands are primarily designed for low flow rates and point source pollution. The first sedimentation pond is generally approximately 1m deep, designed to capture coarse material (pebbles, sand and silt) and is easy to empty with an excavator. The wetland vegetated filters are designed to remove nutrients by plant growth and are about 0.2 – 0.8m deep. Vegetation usually includes species such as bulrush (*scirpus lacustris*), cattail (*typha latifolia*), sweet flag (*Acorus calamus*), common reed (*phragmites*), water horsetail (*Equisetum fluviatile*) and mannagrass (*glyceria fluitans*). However, when the depth in this zone exceeds 0.5m, vegetation cover spreads very slowly, reducing the effectiveness of nutrient uptake. The overflow zones have insignificant water depth and may consist of stones or grass depending on expected runoff intensities. The outlet basin is always situated after the overflow zone to intercept eroded material and is in most cases a second vegetated wetland filter.

In periods of high flow (e.g. storms) nutrients tend to become sufficiently diluted, therefore they bypass the wetland and flow through a pipe directly to the watercourse. This prevents disturbance of the retained sediments and their movement to the wetland.

2.2.9 Can landscape structures contribute to sustainable farming?

The challenge for sustainable agriculture is to make better use of available physical and human resources. To ensure that land use management changes which have positive benefits to the environment will persist, dependency on external systems must be kept to a minimum. This can be done by minimising external input such as artificial fertilisers and pesticides, or regenerating internal resources such as better use of local knowledge, or a combination of both.

Constructed wetlands have the advantage that they are relatively cheap to install if a suitable site can be found for them. Harvesting of plant material removes nitrate from the system. Their construction makes them suitable for treating surface water runoff from hard standing areas (steadings). This is of particular importance if housing for cattle and other livestock is adjacent to a vulnerable watercourse. They require little maintenance once installed. Public curiosity as the ponds develop encourages wider general awareness of methods to improve water quality.

However, there are some disadvantages. Retention capability may decrease with age of wetland. Braskerud (2003) has found that ponds fill with sediment after 10-20 years of use, but excavating the sediment restores retention capability. A suitable optimum site cannot always be located. For example, ensuring long residence of water improves efficiency; therefore gradient within the system needs to be carefully considered. Management plans and budgets must be prepared at the design stage and provision should be made for resolving such unforeseen operational problems. Some technical understanding of nitrogen removal by vegetation is required – so some expert advice on construction and planting is required.

If the UK farming community is to be encouraged to adopt landscape structures such as those described above, there needs to be some form of support to do this. The Norwegian and Finnish Governments provide an example of such support, currently offering up to 70% of construction costs and freely available advice on location and design (Braskerud, 2002).

2.3 Nitrate flux models

2.3.1 Introduction to modelling techniques

This section discusses modelling techniques for water quality modelling, the types and scale of model available, the data sets required for use and their applicability to the farm scale.

For several years there has been concern about the contribution of agricultural activities to environmental pollution, particularly nitrate leached to watercourses. There has been a great deal of research on nutrient export (water quality) and hydrological modelling. Simulation models at a variety of scales have been developed in a number of countries in an attempt to fully understand the processes of nutrient flux and predict future nutrient concentrations under different land use scenarios. For example the 'WWW Server for Ecological Modelling'[2], provides a link to the United States Geological Survey (USGS) 'Surface Water and Water Quality Models Information Clearinghouse' where a searchable database provides summaries of over 30 nitrate transport models and their current applications. Many other model types and applications can be found in the literature, for example (Arheimer and Olsson, 2002; Bouraoui, 1995; McGechan and Wu, 2001). An extensive list of models with their descriptions can be found at the Hydrologic Modelling Inventory website.[3]

In agricultural areas, the main source of nitrate is from biological processes within the soil. It is possible to estimate nitrate losses from land by attributing set values of

[2] hosted at http://dino.wiz.uni-kassel.de/ecobas.html
[3] http://www.usbr.gov/pmts/rivers/hmi/hmi.html

leaching losses to each individual land use. (Arheimer and Olsson, 2002), provide a review of models in use in Europe for water quality modelling. In general the development of a water quality model is likely to require information on some or all of the following:

- The terrestrial nitrogen cycle, including the effects of management practices;
- Hydrological behaviour;
- Nitrogen transformations within the stream;
- History of land management and cropping ;
- Timing and quantity of nitrogen inputs (mostly fertilisers but also atmospheric deposition).

However, before choosing a suitable water quality model, the user must decide what the required output of the model will be, as this will determine what type, what scale and what data are appropriate. Models are often mixtures of different model types, and there is typically a transition from explorative to predictive models. The choice of model should balance the degree of complexity required with uncertainty of the input parameters (Skop and Sorensen, 1998). Models come in three basic types:

Empirical models - also known as black box models - transform input data to output data. These models are relatively simple requiring little data, and can provide simple budgets of nutrient loads entering water-courses. However, physical processes are not simulated and extreme events cannot be successfully modelled. Such models are not easily transferred to new sites.

Conceptual models simulate physical processes based on major simplifications. Each physical component of the system or process is modelled in a simplified manner. This type of model is useful when detailed information on the processes taking place is lacking.

Physically-based (mechanistic) models use theoretical equations on physical, chemical and biological parameters to simulate the internal mechanisms of the system.

In addition to model type, spatial and temporal scales can also be incorporated. For example:

Lumped models assume the catchment to be homogeneous, and variables are stated as averages over the whole of the catchment area. The spatial variation of parameters such as rainfall, storage in the saturated zone, topography, land cover, management practices, and soil types, are averaged (lumped) together as a single unit. Lumped models are useful for making generalisations for large areas (i.e a whole catchment) e.g. HEC-1.

Distributed models e.g. SHETRAN (Parkin, 1995) include the spatial variability of watershed characteristics. Hydrological, climatic and management parameters are assumed homogeneous within a cell, but these can vary from cell to cell. However these suffer from high computational expense which limits their practical use for calculating flows at different locations. Furthermore, the user may be forced to adopt a relatively coarse grid resolution in order to model catchments larger than a few km^2. This tends to introduce additional problems in the identification of parameter values.

Semi-distributed models apply conceptual functional relationships to a small number of homogeneous parts of the catchment that are treated as 'lumped units'. For example TOPMODEL (Beven 1984) is capable of accounting for topographic characteristics of the catchment and can be adapted to account for some of the catchment heterogeneity, but is still limited to calculation of flows at the catchment or subcatchment outlet. The Integrated Nitrogen Catchment model (INCA), developed by Aquatic Environments Research Centre (AERC, Reading), integrates vertical and horizontal catchment and river processes (Whitehead *et al* 1998a; 1998b;) and has been used in ten countries and seven UK research projects (Wade *et al.*, 2002) including the River Tweed (Jarvie *et al.*, 2002).

Stochastic and fuzzy models - allow for some randomness or uncertainty in the possible outcomes due to uncertainty in input variables, boundary conditions or model parameters.

Steady-state models - have no time component but describe average temporal conditions for the period studied.

Dynamic models – incorporate a time dimension with specific rates for different processes, creating time-series for temporal variability. Such models can simulate seasonal, annual, decadal variations

In essence, model characteristics can be seen as moving from simplicity to complexity (figure 2.4. below). This can be in terms of model processes, temporal and spatial scale, data requirements, and so forth.

Figure 2.4 Summary of model characteristics

	Simplicity	→	**Complexity**
Processes	Empirical	Conceptual	Mechanistic
Spatial dimension	Lumped	Semi-distributed	Distributed
Temporal dimension	Steady state	Dynamic	Continuous
Data requirements	Readily available / literature	Mix of literature and site specific	Catchment specific
Examples	Export Coefficient Model	INCA	SHETRAN TOPDOG

Appropriate choice of model is one of the key issues to be addressed in a study of water quality. In recent years the capability of modern computers has increased so much that processor speed and size of hard drive are no longer issues in model choice. Choice more often depends on the availability of the data sets required to make the model run. In simple models data sets are more likely to be readily available from official sources or can easily be gathered in the field. In complex models data may be more difficult to gather and require long periods of fieldwork or complex equipment and data preparation. In addition the computer system on which the model runs may be of issue to the user. Not all water quality models run on the Microsoft WINDOWS operating system. Some models require specialist operating systems such as UNIX, using complex computer coding in programming languages such as Fortran or C++. These models require technical experts with programming skills to ensure the model runs correctly. In order for a model to be user-friendly in the wider academic community and beyond, it needs to be intuitive, or at least with a handbook that leads the user through each stage of model calibration and validation.

The literature provides many reviews of existing water quality simulation and prediction models. For example, McGechan and Wu (2001) have reviewed a selection of physically-based European models that study processes in arable land from the application of inorganic fertilisers and livestock manures.

In addition there are now comprehensive web based resources on ecological models. A comprehensive, searchable register of models can be found at e.g. http://eco.wiz.uni-kassel.de/ecobas.html. This website provides a full summary of models, including technical details, author and so forth. A brief summary of the more popular models is included in table 2.2 below.

Table 2.2 Summary of hydrological models

Acronym / Name	Type	Characteristics	Authors
AGNPS Agricultural Non-Point Source Model	Event based distributed parameter model	Predicts soil erosion and nutrient transport/loading from agricultural watersheds for real of hypothetical storms	US Dept of Agriculture: Agricultural Research Service (USDA-ARS)
ANSWERS Areal Nonpoint Source Watershed Environmental Response Simulation	Event-orientated, distributed parameter model	Simulates behaviour of agricultural catchment	(Engel et al., 1991)
CREAMS Chemicals, Runoff and Erosion from Agricultural Management Systems	A field-scale model	Predicting runoff, erosion, and chemical transport from agricultural management systems	United States Department of Agriculture (USDA) 1980
GLEAMS Groundwater Loading Effects of Agricultural Management Systems	Continuous simulation field-scale model	Evaluating the effects of management practices on movement of agricultural chemicals in the plant root zone.	Leonard, Davis & Knisel United States Department of Agriculture (USDA).
HEC-RAS Hydrologic Engineering Centre-River Analysis System	Hydraulic modelling software for open channels, bridges and culverts	One dimensional steady and unsteady flow calculations	http://www.wrc-hec.usace.army.mil/
KINEROS Kinematic Runoff and Erosion Model	Event based physically based model	Determines the effects of artificial features such as urban developments small detention reservoirs on flood hydrographs and sediment yield.	USDA-ARS
SWAT Soil & Water Assessment Tool	A river basin scale model for large, complex watersheds.	Predicts the effect of management decisions on water, sediment and chemical yields in ungauged catchments	Arnold & Srinivasan Buckland Research Centre, Texas

RZWQM The Root Zone Water Quality Model	A one-dimensional (vertical in the soil profile) process-based model	simulates major physical, chemical, and biological processes in an agricultural crop production system, including simulation of a tile drainage system.	USDA-ARS-GPSR, Fort Collins
TOPMODEL	Spatially distributed rainfall-runoff model	Distributed predictions are based on an analysis of catchment topography	Beven (1979)
WEPP Water Erosion Prediction Project	Process-based, distributed parameter, continuous simulation,	Models hillslope erosion processes (sheet and rill erosion), and simulation of hydrologic and erosion processes on small watersheds.	http://topsoil.nserl.purdue.edu/nserlweb/weppmain/
MODFLOW	MODular three-dimensional finite-difference ground-water FLOW model	simulates steady and non-steady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined.	USGS – no longer freely available

2.4 The use of Remote Sensing in land use mapping and water quality modelling

2.4.1 Introduction to Remote Sensing

Remote Sensing (RS) is:

> *"the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation"* (Lilliesand and Keifer, 2000).

Although the use of Remote Sensing has a relatively short history, it has great potential and is becoming more widely used in research where agricultural change and impacts are studied. In such studies, land use and land cover must be classified. RS image data are usually acquired either by satellite or by airborne multispectral sensors. In the past it was very expensive to acquire data as well as support the computer resources necessary to process, analyse, and report findings. However, advances in remote sensing and GIS technologies, along with improving computer hardware and software technologies, have now made this type of analysis a viable tool in research and planning practice (Dallemand and Vossen, 1994; Logsdon *et al.*, 1996). Projects using such technology include the EU MARS project (Monitoring Agriculture through Remote Sensing techniques [4]), the US Large Area Crop Inventory Experiment (LACIE [5]) and the US Agricultural and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS [6]).

Until 1991, 70% of the land surface of Great Britain had been mapped using a costly combination of aerial photographs and surveyors' fieldwork (Cherrill *et al.*, 1995). Then the availability of 30m resolution image data from Landsat-5 TM acquired between 1988 and 1990 enabled the Institute of Terrestrial Ecology to produce the first complete ITE Land Cover Map of GB classified with 25 land cover types (*ibid*).

[4] http://www.marsop.info/
[5] http://www.house.gov/science/charter_br_09-28.htm
[6] http://ceos.cnes.fr:8100/cdrom-97/ceos1/satellit/vegetati/overview.56/descript.htm

It is now estimated that approximately 100 new satellites have been launched during the 10-year period between 1996 and 2006. Together with the rapid development of high-resolution airborne data acquisition technology, there is a large selection of remote sensing data of the Earth's surface with respect to spatial, spectral and temporal sampling (Rogan and Chen, 2004).

Remote sensed imagery is widely used in land use and land cover classification because it is capable of providing valuable high-resolution information about land cover in areas in which such data cannot be easily gathered by other means and its applications can contribute to the achievement of sustainable and efficient agricultural practices. The literature, for example (Lilliesand and Keifer, 2000; Mather, 1999; Richards and Jia, 1999; Sabins, 1997) summarises the advantages of using remote sensed imagery are:

- Large areas can be imaged quickly and repetitively;
- Images can be acquired with a spatial resolution that matches the scale required in a study;
- Data can be readily exported/imported to GIS mapping software;
- Problems of access encountered in ground surveys are eliminated;
- It can 'see' features beyond human visible range;
- Multi-band images enhance the contrast and conditions of features;
- Skilled interpretation is faster and less expensive than ground survey;
- It achieves a permanent and objective data set;
- It provides a multi-functional data set – different users can use the same data set in different research areas.

Despite these advantages, some limitations with the technology still exist. These include: potential limitations with spatial, spectral and temporal resolutions of the various sensors; problems with all-weather capability (not all sensors can 'see' through cloud); costs of data collection and data purchase, and problems with data analysis and interpretation, such as the identification of particular crop types, especially those that are subject to different fertiliser practices. While remote sensing is a useful technique, its main use is still to supplement ground surveys.

2.4.2 Using RS imagery in land cover classification

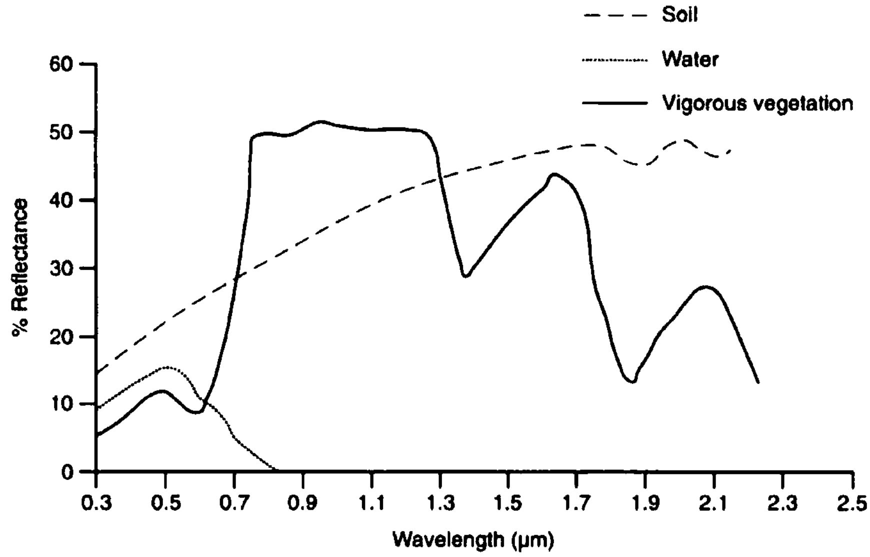
Remote sensing systems measure electromagnetic radiation (EMR) energy reflected or emitted from the Earth's surface at a range of fixed wavelength positions known as spectral bands (Lilliesand and Keifer, 2000; Mather, 1999; Richards and Jia, 1999). For example, the NERC ARSF Airborne Thematic Mapper (ATM) provides data in 11 fixed wavelength position bands in the visible, near/short/ thermal infrared many of which approximate to those of Landsat data (table 2.3 below).

Table 2.3 Spectral range of sensors

ATM band	Spectral range (μm)	Landsat TM band	Position
1	0.42 - 0.45		Blue-green
2	0.45 - 0.52	1	Blue
3	0.52 - 0.60	2	Green
4	0.605 - 0.625		Red
5	0.63 - 0.69	3	Red
6	0.695 - 0.75		NIR
7	0.76 - 0.90	4	NIR
8	0.91 - 1.05		NIR
9	1.55 - 1.75	5	SWIR
10	2.08 - 2.35	7	SWIR
11	8.5 - 13.0	6	TIR

The visible/infrared/thermal range is particularly useful for land cover studies. Reflected measured energy in the visible/infrared range is determined by pigment, moisture content and cell structure of vegetation, the mineral and moisture content of soils and level of sediment in water (*ibid*). For example, figure 2.5 below shows the spectral reflectance curve for vegetation, water and soil and how these are significantly different.

Figure 2.5 Idealised spectral reflectance curves for vigorous vegetation, soil and water



Source: (Mather, 1999)

In the digital image, each pixel will comprise a digital number (DN) that defines the spectral signature due to the absorption and reflectance properties of different surfaces. This is why multi-band remote sensing is invaluable to studies of land cover. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 μm), whereas the cell structure of the leaves strongly reflects near-infrared light (from 0.7 to 1.1 μm). As the extent of vigorous growth (of for example, leaves) affects these wavelengths of light, using bands in these wavelengths enables the spectral signature for different vegetation species to be identified. However, as will be seen, many vegetation types are spectrally similar and one of the key issues in land cover classification research is how to overcome problems of spectral inseparability.

2.4.3 Land-use classification research

Remote sensing imagery has been used in land use classification since the early 1980s, at a variety of scales and using different sensors. The following table (table 2.4) includes examples that illustrate the range of studies that have been undertaken. This will form the background to a brief discussion about the relative merits of the methodologies and techniques used.

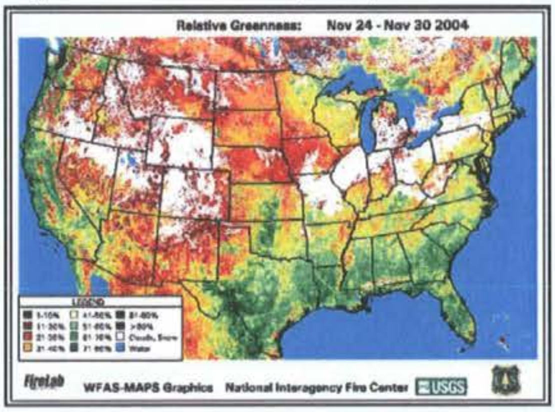
Table 2.4 Summary of selected studies using Remote Sensing for land use classification

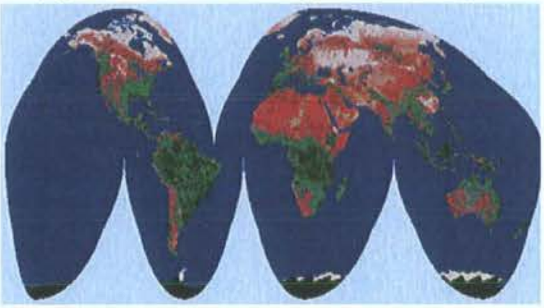
Author	Study area / scale	Techniques	Conclusions
Adinarayana et al., (1994)	Indian Continent	Combines satellite data with GIS topographic raster and local knowledge	MLC alone could not distinguish seasonal variation in upland /low-lying areas. Combining GIS data extended accuracy of land cover maps
Cherrill et al., (1995)	National (GB)	Landsat-5 TM First ITE Land Cover Map of Great Britain produced by RS methods	Satellite imagery is based on a 25m grid cell, providing a spatially referenced inventory of land cover. However, minimum mappable units e.g. minor roads, tracks and small areas such as woodlands can be omitted leading to discrepancies between ground survey and RS imagery
Binaghi et al., (1996)	Regional Po river basin, Italy	Landsat TM bands 2 & 7 Fuzzy supervised classification to identify rice crops	Identified five land cover classes. Success depends on spectral separability of classes, a large number of classes requires more detail are harder to separate.
Haack and English, (1996)	National Scale (Afghanistan)	Landsat TM bands 3-7-4 (sensitive to longer wavelength radiation) –	Manually traced polygons on areas of similar colour identified as 'active agriculture'. National land cover is an enormous task but useful. RS is an effective data source, it can detect changes over time and be baseline for future monitoring
Friedl and Brodley, (1997)	Continental scale	Decision Tree Classifier to use NDVI at 1km scale	Difficult to accurately distinguish between some vegetation classes

Thomson et al.,(1998)	UK river corridors and inter-tidal zones	CASI data using unsupervised and supervised methods of classification	Unsupervised classification -serious deficiencies in differentiating woodland and other semi-natural vegetation; water and shaded woodland. Maximum Likelihood Classifier – confusion between vegetation types such as heather, deciduous woodland and rough grass
Aplin et al., (1999, 2001)	Urban and rural land cover in St Albans UK	Four spectral bands from CASI data	Eight land cover classes in per-field classification, but errors in some non-urban land cover.
Foody, (2000)	Local scale >1 km^2 Swansea	ATM 1.5m resolution – 11 bands to classify 3 distinct land cover types using fuzzy c-means (FCM) and possibilistic c-means (PCM) classification to identify mixed pixel classes	Where untrained classes are present, FCM (relative measure of class membership) is weaker than PCM. PCM provides an absolute measure of the strength of class membership indicating typicality which may be more appropriate when untrained classes are present. The calculation of memberships from the PCM is simple, based on the distance between a pixel and the class centroid, and could be produced alongside, a standard FCM analysis.
Hill et al., (2001)		ALTM and 12 band CASI, trained to produce a DEM and assign 4 land cover classes	Maximum radiance likelihood on parcels
Song et al., (2001)		Landsat TM bands – when and how to correct for atmospheric effects	Atmospheric effects can prevent proper temporal change interpretation. Single date images do not need atmospheric correction if training data and image are on the same scale.
Haboudane et al., (2002)		Chlorophyll content to assess nutrient status for precision farming	

The production of an accurate land cover map requires the precise classification of the land cover composition of each pixel. Commercial image processing software packages are readily available that enable this classification process, including packages such as PCI Works, ENVI, ERDAS IMAGINE, ArcGIS[7]. Functions within these packages provide many methods of classification and full descriptions of the various classification algorithms can be found in textbooks such as (Lilliesand and Keifer, 2000; Mather, 1999; Richards and Jia, 1999; Sabins, 1997). In brief, though, classification may be 'unsupervised', i.e. one that seeks to group together cases by their relative spectral similarity or 'supervised', one that allocates pixels on the basis of their similarity to a set of predefined classes that have been spectrally similar (Foody, 2002). The resulting classified image then becomes a thematic map of the region of interest. Thematic maps may be at the global / continental scale (figure 2.6 below), for example the US Geological Survey gathers data from the Advanced Very High Resolution Radiometer (AVHRR) Satellite for the 1.1km spatial resolution vegetation greenness maps derived from the Normalized Difference Vegetation Index (NDVI).

Figure 2.6 Thematic maps at a) continental [8] and b) global [9] scale: NDVI greenness maps





At the national / regional scale Landsat- 5 TM, resampled to 25m data, has been used to compile the ITE land cover map of Great Britain (Cherrill *et al.*, 1995). At the

[7] It is not within this research to provide a review of available image processing software as most provide similar functions and use is of personal preference and research requirements.
[8] http://www.fs.fed.us/land/wfas/wfas11.html
[9] http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/LAND_BIO/ndvi.html

local scale Compact Airborne Spectrographic Imager (CASI) gathers data at a spectral resolution of 0.5 – 10m and the Airborne Thematic Mapper (ATM) provides 5 - 25m resolution data, enabling very high resolution land cover mapping. However, a thematic map is only valuable if it provides an unbiased representation of the land cover of the region it portrays. Therefore, the extent of classification accuracy must reflect the scale of study and is of paramount importance to researchers. Typically, accuracy is taken to mean the degree to which the derived image classification agrees with reality or conforms to the 'truth'(Foody, 2002).

Much of the literature on the use of RS data in classifying land use highlights the issues of spatial resolution, methods to overcome problems of accuracy and spectral inseparability between vegetation types.

At the global and continental scales it may be sufficient to classify areas which support vegetation such as the NDVI greenness maps, and such images are particularly useful to demonstrate temporal change and trends over very large areas. At the national scale Haack and English (1996), working on land use change in Afghanistan, found that Landsat data produced regions of 'similar colour' and they could identify areas of 'active agriculture' by drawing polygons around these regions. Although this proved to be an 'enormous but useful task' the resulting maps provide a baseline for monitoring future changes in agriculture.

However, in compiling the ITE Land Cover Map of Great Britain, Cherrill *et al.* (1995), found the spatial resolution of Landsat data created problems and that the size of minimum mappable unit can lead to inaccuracy of mapping. Satellite imagery based on a 25m grid cell, when compared to ground survey, misclassified small areas of land use. These included small areas of woodland, minor roads and tracks. This suggests that Landsat data with 30m pixels may be useful in producing land cover maps at the national or regional scale, but at the local scale a higher resolution is required.

Spectral separability of vegetation types is an important issue to be addressed. Adinarayana *et al.* (1994) found that using a Maximum Likelihood Classifier (MLC) technique on its own had difficulties distinguishing between agricultural land in low-lying areas and upland vegetation in the growing season. They achieved improved results by combining RS data with other data sources such as topographic maps in a GIS to separate low-lying and upland areas. Binaghi *et al.* (1996), in trying to classify agricultural land in the Po river basin found, that a large number of land cover classes requires more detail and are therefore harder to separate using the MLC technique. To overcome this problem a 'soft' Fuzzy Classification technique was developed whereby there is a gradual transition from membership to non-membership in uncertain classes using a simple linear model such as that described by Mather (1999).

Further work on land use classification using various unsupervised and supervised techniques has continued to show serious deficiencies in differentiating certain vegetation types even at 1.5m spatial resolution (Aplin and Atkinson, 2001; Aplin *et al.*, 1999; Foody, 2000; Hill *et al.*, 2001; Thomson *et al.*, 1998). In an attempt to address this problem, machine learning classifiers such as Decision Trees and Artificial Neural Network Classifiers have been introduced (Rogan and Chen, 2004). The decision tree technique uses a multistage hierarchical approach to discriminate between spectral classes, breaking up complex decisions by recursively partitioning a data set into purer subsets on the basis of a set of tests applied to attribute values (Pal and Mather, 2001). However, accuracy of the decision tree requires care in choice of input data in terms of spatial resolution and spectral bands. Using 1km resolution data with the NDVI ratio, (Friedl and Brodley, 1997) still had difficulties accurately distinguishing between vegetation classes. This is not entirely unexpected as NDVI is a description of greenness rather than a unique spectral signature. The decision tree classifier has many advantages over other classifiers in that it is capable of incorporating parameters from a range of multispectral bands and/or images. This enables the user to determine not only the data set (bands or data sources) to be interrogated, but also the specific parameters (e.g. spectral range from three or more bands, topographic images or other imagery) and it should therefore be possible to describe a unique identifier for particular cereal crops when growth stage differences are most pronounced.

2.4.4 Summary

By careful choice of imagery, data source and classification method, RS imagery can be used to create an accurate land cover map. If an RS dataset is available at relatively low cost, covers areas hard to access by other means and is readily available for incorporation into a GIS, this can then be used to analyse the potential benefits of landscape structures suitable for water quality management.

2.5 Policy instruments & national guidelines for water quality

This section reviews relevant EU and UK legislation and policy instruments designed to protect water quality that have been introduced since the 1980s. This approach to regulation will be compared to an alternative method to tackling environmental problems; the 'bottom-up' community based approach that has been used in Australia.

2.5.1 Introduction to water quality policy

The key theme of this research is evaluating the impacts of policy and land use on water quality. Water pollution as a result of high concentrations of nitrate is now a major environmental concern not only in Europe but also globally. Agricultural activities are a major source of these pollutants (Carton and Jarvis, 2001), as a result of the intensification of agriculture, the increasing use of fertilisers, and the specialisation and concentration of crop and livestock production. In an attempt to understand why there is still a nitrate problem despite twenty years of UK and European Union legislation there needs to be a discussion of the factors that have contributed to high concentrations of nitrate in surface waters and the legislation that attempts to address this problem.

2.5.2 Agriculture in context

Agriculture in the post-war years in Europe and the UK was in a very poor state. Production was low, accounting for severe food shortages, and there had been a long period of under investment in the farming industry. In an attempt to improve agricultural efficiency, there was a shift in emphasis. In 1973, the UK joined the EU (then known as the EEC) and was able to benefit from the guaranteed level of market prices and intervention through the Common Agricultural Policy (CAP). Then a 1975 UK Government White paper stated 'The Government takes the view that a continuing expansion of food production in Britain will be in the national interest' (Addiscott *et al.*, 1991). This resulted in the introduction of a series of measures. For example: land drainage schemes designed to bring more marginal land into arable production; direct Government financing of research and education for the promotion of labour saving/yield increasing technology; and support for farmers to adopt new technology through Capital Grants and input subsidies. Between 1975 and 1995 there were further significant changes in European agriculture. Statistics collected by European Commission (European Commission, 1999) indicate the major trends across Europe were:

- 12% decrease in permanent grassland;
- 12% increase in arable land for high-yield forage crops;
- Traditional mixed farms replaced by specialist farms consolidating the major producing areas in an attempt to achieve short-term profitability;
- Increase in farm size leading to more 'intensive industrial' agriculture units;
- Grubbing up of hedges to increase the size of fields to accommodate large machinery;
- Over-production, particularly in milk products and cereals, leading to surpluses and falling market prices.

During this period there was little consideration of the effects of farming on the environment. Many of these changes had negative impacts on biodiversity, soil quality, flow and quality of water, and landscape which have continued to the present time.

CAP reforms during the early 1990s endeavoured to control the area under cereal production by the introduction of set-aside[10]. However, rather than decrease the

[10] Set-aside is premium arable land taken out of production in an attempt to reduce cereal output.

cereal output as intended, production increased due to further intensification of production on the reduced land area and increased use of fertilisers. In addition, this round of CAP reform did not move towards an integration of environmental benefits and sustainable farming (Poiret, 1999). It was not until the proposals under 'Agenda 2000' that the European Commission sought to tackle the agriculture and environment issue by introducing a more structured and consistent policy of agricultural aid and environmental protection.

2.5.3 The history and impact of EU water quality legislation in the UK

During the 1980s, legislation was introduced to tighten up the control of water quality and in particular the issue of nitrate in water. At that time, some UK water suppliers were still working to a World Health Organisation (WHO) upper limit of 100mg/l NO_3 (Osborn and Cook, 1997). The EC Directive on Drinking Water (80/778 EC) was a result of the growing concerns about health and environmental risks from high concentrations of nitrate in drinking water. This set a maximum admissible concentration of 50 mg/l NO_3 and a desirable guide level of 25 mg/l to be achieved by 1985.

The UK Water Act 1989 introduced the Nitrate Sensitive Areas (NSA) scheme as a particular section with the aim of establishing the effects of farming practices on nitrate levels in aquifers. The Nitrates in Water Directive (91/676 EC) followed this, in which two new objectives were laid down:

- To avoid a concentration of nitrate in surface and groundwater above 50 mg/l NO_3;
- To avoid eutrophication of surface, estuarial, coastal and marine waters.

Under this Directive, water sources which could be affected by nitrate pollution above the 50 mg/l permitted maximum (if protective action was not taken) had to be identified, then designated as Nitrate Vulnerable Zones (NVZs). By this time it was generally agreed that the increased use of chemical fertilisers on agricultural land was a major contributor to diffuse pollution and that if the application of these fertilisers could be reduced this would go some way to limiting nitrate levels in drinking water.

This Directive sought to tackle the problem of water pollution not just as a 'cleaning up' programme, but to encourage prevention of pollution at source.

EU water quality legislation was brought together in a co-ordinated manner during the 1990s, culminating in the comprehensive Water Framework Directive (2000/60/EC). The key components of this Directive will ensure European waters are protected according to a common standard and must be delivered by 2012. All EU Member States must now put in place:

- A system of management of natural water environment based around natural river basin districts;
- Co-ordinated programmes of measures to achieve at least "good status" for rivers, lochs, estuaries, coastal waters and underground waters.

The measures introduced from these key pieces of legislation directly impact on day-to-day farming practices and have been the subject of research. This section of the literature review will examine these effects and how recent findings can be incorporated into this research.

2.5.4 Nitrate Sensitive Areas and Nitrate Vulnerable Zones

The Nitrate Sensitive Areas (NSA) scheme introduced in 1990 brought a change in political thinking with regard to water quality. Government compensation became available to farmers participating in basic or premium options of a management plan for five years. The compensation would make up economic losses resulting from significant changes to farming practices that went beyond 'good agricultural practice'. The scheme demonstrated initial successes with nitrate losses falling from 55 kg/ha in 1990/91 to 37 kg/ha in 1994/5 (Lord *et al.*, 1999). A further 22 NSAs were designated in 1994 and the voluntary measures were then made mandatory in the Nitrate Vulnerable Zone (NVZ) scheme of 1996. An NVZ is described as a catchment where nitrate concentrations in sources of public drinking water exceed, or are likely to exceed, the EU limit of 50 milligrams per litre (mg/l) (also referred to as 11.3mg/l nitrate-N in the literature). However, the scheme was closed to new entrants in 1998 as part of the Government's Comprehensive Spending Review. Instead, farmers were encouraged to follow uncompensated 'Good Agricultural Practice' guidelines set out by MAFF (the precursor of Department for Environment, Food and Rural Affairs (DEFRA)). Initially NVZ designations applied to only 8% of England and Wales. In December 2000 the European Court of Justice ruled that the UK had failed to implement the requirements of the 1991Nitrates Directive fully, stating that it applied to all ground and surface waters so as to reduce the risk of eutrophication as well as to protect drinking water sources. As part of its commitment to the WFD the UK Government therefore had to take action to comply with the Court's judgment and complete its implementation of the Directive fully or face substantial daily non-compliance fines (DEFRA, 2002). By December 2002 the area within English and Welsh NVZs had increased to 55% and 3% respectively and in Scotland newly designated NVZ account for 18% of the land area (SEPA, 2002a).

2.5.5 The Scottish approach to the WFD

Under devolved powers the Scottish Executive can introduce measures relating to EU legislation separately from the rest of the UK. The WFD requires a River Basin Management Plan (RBMP) be put in place, and within this there should be a programme of measures to achieve the environmental objectives. This will be implemented through the Water Environment and Water Services (Scotland) Act 2003 (WEWS)[11]. To aid this process, the Scottish Office commissioned research by the British Geological Survey (BGS) to identify areas where nitrate pollution occurs in Scottish waters and from this, four areas of Scotland were designated as NVZs from January 2003 (BGS, 2001; SEERAD, 2003b), shown is see figure 2.7 below.

Among the newly designated sites is the Edinburgh Lothian and Borders NVZ, which incorporates the study area (see figure 2.8). Farmers within an NVZ must comply with a mandatory Action Programme, set out in the document 'Guidelines for Farmers in NVZs' and regulated by (SEERAD, 2003b). In addition to the mandatory measures of the NVZs, the Scottish Environment Protection Agency

[11] WEWS - http://www.opsi.gov.uk/legislation/scotland/acts2003/20030003.htm

(SEPA) has established a proactive approach to water quality issues with the establishment of the Diffuse Pollution and Habitat Enhancement Initiatives.

Projects within these initiatives have demonstrated that methods of farming practice, such as the creation and management of wetlands, can act as a sink for nitrate; field and water margins can protect watercourses from pollution as well providing rich habitats for wild life (Frost *et al.*, 2002; SEPA, 2002b). Of particular interest to this research is the development of the Tweed Catchment Management Plan. Written by the Tweed Forum, a not-for-profit organisation, the document highlights areas where 'a new, strengthened system for the protection and improvement of water quality and dependent ecosystems is required' (Tweed Forum, 2003). The Tweed Forum together with SEPA also support a local forum, the Leet Catchment Management Group, which works with local farmers and other expert institutions to improve water quality and habitats in the Leet Water catchment.

The introduction of NVZs and the institutional, proactive approach to tackling the problems of water quality has been of great influence in the choice of the Leet catchment and SEPA, itself has encouraged the development of this research.

Figure 2.7 Nitrate Vulnerable Zones (Scotland) 2003

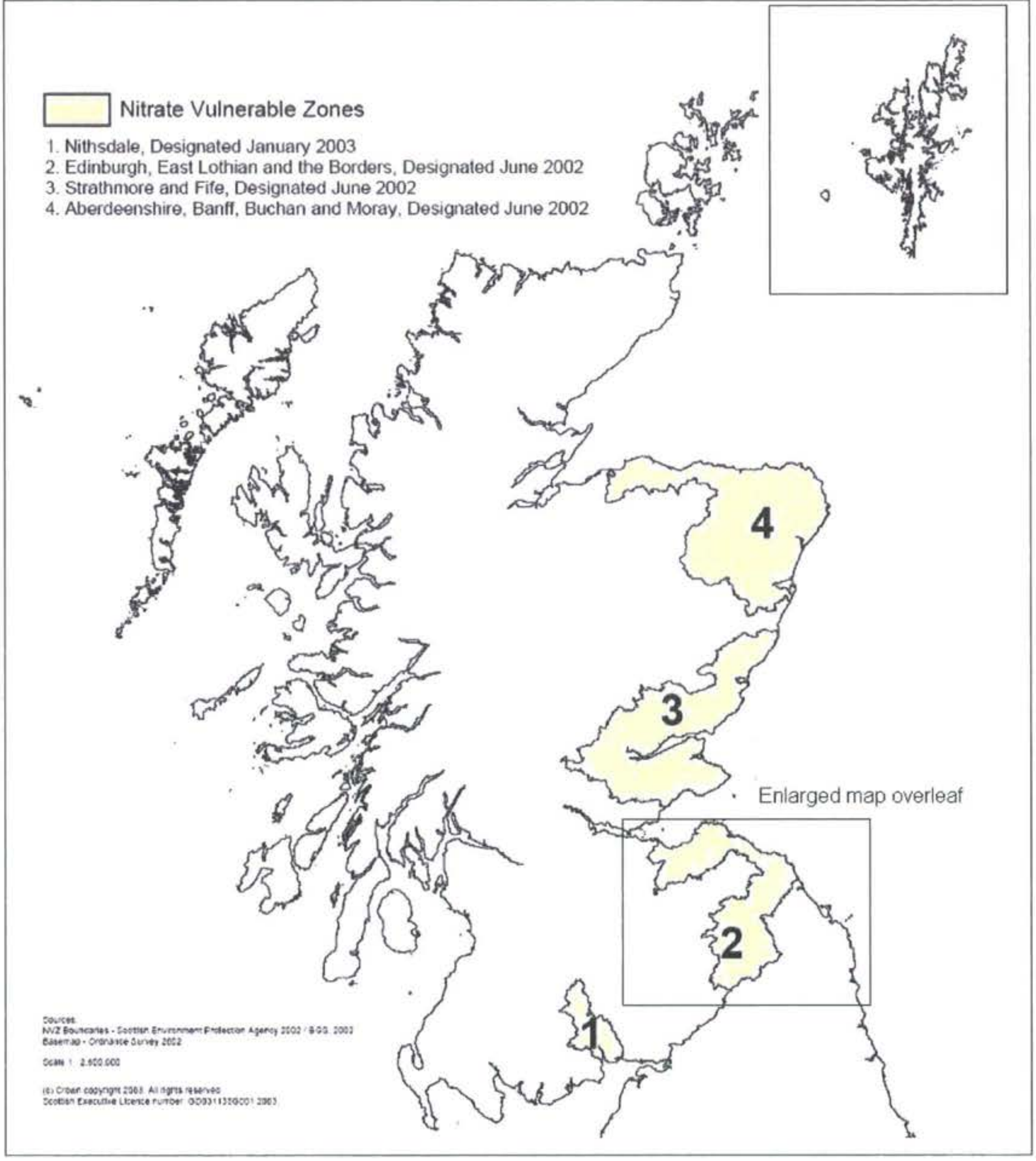
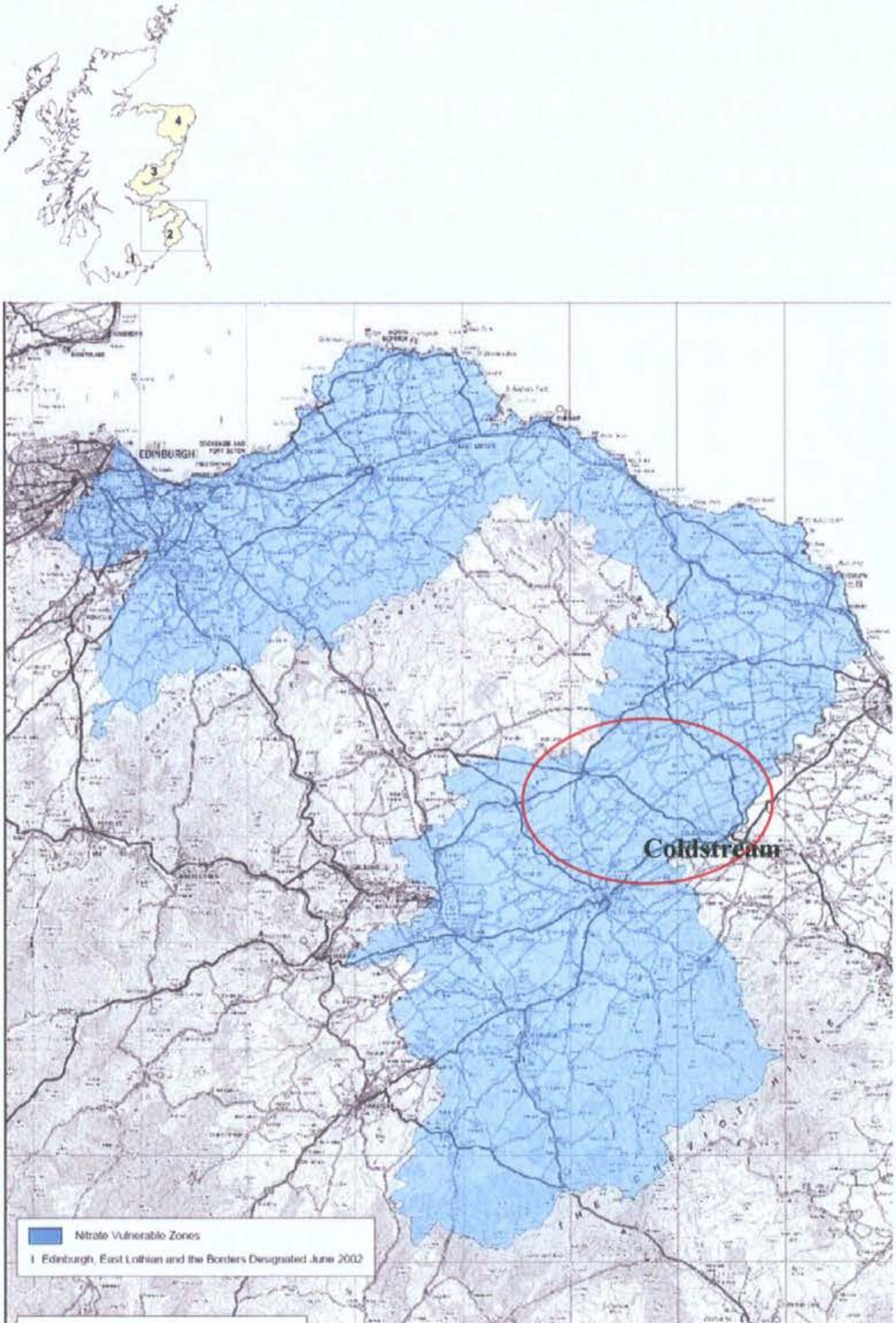


Figure 2.8 Edinburgh, East Lothian and the Borders NVZ (study area highlighted)



2.5.6 Common Agricultural Policy reform and Land Management Contracts

Environmental considerations are now a major concern of the common agricultural policy (CAP). Decoupling[12] (changing the way farm payments are made) will help make significant strides towards meeting the objectives of the Agriculture Strategy and will create opportunities for a more market-oriented, competitive agriculture (DEFRA, 2004; SEERAD, 2003a). An integral part of the latest round of reforms is that farmers should observe a certain basic level of environmental practice as part of CAP support payments, but farm management beyond basic good agricultural practice and compliance with environmental legislation should be paid for by society through agri-environmental programmes (European Commission, 1999). At present the key agri-environment scheme available to the farming community is the Rural Stewardship Scheme[13] (RSS) (SEERAD, 2003d).

As part of CAP reform, the Scottish Executive is intending to introduce Land Management Contracts (LMCs) and these will directly impact on the farming community. SEERAD believes LMCs will streamline existing subsidy schemes. This is an approach endorsed by the Agriculture and Environment Working Group (SEERAD, 2003c). LMCs aim to provide support payments at basic and higher levels in return for a whole farm system that delivers environmental as well as social and economic benefits. SEERAD suggests a Three-tier model of farming. Tier One provides base payments for all farmers opting in and following good agricultural practice to replace the proposed single farm payment; Tiers Two and Three requiring management practices that bring additional environmental benefits would attract additional funding as farmers choose options that best suit their farming conditions. The potential of LMCs to deliver the requirements of WFD will be explored further as land use change scenarios are modelled.

[12] As part of CAP reforms agreed by Member States in 2003 there will be a change in the way payments to the farming community are made. There will no longer be a link between farm support and production subsidies.
[13] A full description of agri-environment schemes and their requirements will be included in Chapter Seven.

2.6 The Community Based Approach – Landcare Australia

It has been shown that diffuse agricultural pollution is a significant contributor to problems of poor water quality in the EU. There has been a move to implement policy initiatives to improve water quality, but despite more than 20 years of nitrate legislation in the UK, the problem persists. Are there lessons for improving water quality and encouraging a change in stakeholders' attitudes that can be learned from other parts of the world?

2.6.1 Concepts of Landcare

Australia, like the EU and the United States has enjoyed a very high standard of living through exploitation of its natural resources, including agricultural activities. In recent years, however, the sustainability of those actions has been questioned. Some estimates state that degrading environmental resources including water quality and loss of bio-diversity equates to a value of about 1.5 billion Australian dollars annually in lost production (Sutherland and Scarsbrick, 2001). In 1989, there was an attempt to turn this state of affairs around. Representatives from the National Farmers' Federation and Australian Conservation Foundation convinced the Federal Government to commit a decade of financial support amounting to $700 million, to restore and enhance Australia's natural resources under the umbrella organisation Landcare (Landcare, 2003). Landcare Australia is a model for achieving positive environmental and farming outcomes with social and economic benefits for the whole community, comprising the four pillars of: bipartisan political support; conservation and farmer group endorsement; community awareness and participation; and national marketing and awareness.

The organisation itself is not-for-profit, with more than 2000 voluntary, local community-driven Landcare groups spread across the whole of Australia. Although increasing soil salinity is the most fundamental water issue to Australian agriculture, the ethos of Landcare indicates how a bottom-up approach can generate local commitment to sustainability and encourages cooperative approaches to the uptake of sustainable farming methods. One of the primary roles of Landcare is the funding of full-time local facilitators with the aim of helping the voluntary groups make the best use of their resources (both human and physical), develop a shared sense of direction, encourage skilled listening, ask the right questions at the right time, providing occasions, organising encounters and stimulating interaction among target stakeholders.

Does Landcare Australia offer an insight into the benefits of adopting a bottom-up approach as a method for improving water quality in agricultural communities? Anna Carr discusses the benefits of the bottom-up approach in her PhD thesis (Carr, 1994). In this she states the bottom-up approach can:

- Develop a meaningful notion of what good land management is within the local community; it encourages a 'sense of community' and 'sense of place'. Its members can integrate and examine issues not only from differing points of view but also from a multi-disciplinary perspective;

- Develop cooperative approaches to tackle particular issues such as biodiversity, or catchment hydrology which require coordinated collective action;

- Allow groups to become action-focused; taking on projects that are founded on experiential learning and face-to-face contact;

- Recognise that landholders have valuable knowledge and recognise the importance of 'local ways of knowing';

- Recognise the importance of farmers sharing information and ideas among themselves and not simply relying on 'the expert' for direction and assistance. In this way groups may be more willing to ask questions and overcome bureaucratic barriers, whereas an individual may feel intimidated;

- Open new avenues for local and traditional environmental knowledge to be taught by landholders to government agencies and officers;

- Encourage the learning process as a by-product of group membership, therefore creating equality, respecting diversity, drawing on individual experiences, and encouraging social interaction.

This bottom-up approach sees social learning as a collective experience determined by the relationships within a group and that small groups can support their members and provide a safe context for experimentation.

2.6.2 Criticisms of the Landcare approach

It has been argued that there is a preoccupation with funding allocations at local/regional/state/federal levels and on what it is spent. Under the Natural Heritage Trust, government funds for natural resource management will be delivered through the regional investment model developed by the National Action Plan for Salinity and Water Quality. Under this model, regional communities participate in putting together regional plans which outline the most important issues for action and funding.

The early years of Landcare programme were the subject of much scrutiny. The take-up of environmental improvements had been much slower than expected. This was in part due to patronising attitudes towards farmers by scientists and extension officers (Vanclay, 1992). However, Vanclay found that slow up-take of new ideas and farming methods was 'objectively rational' for the farmers due to inherent barriers to the adoption of new ideas. These barriers are described as:

- Complexity, risk and uncertainty – the more complex an innovation, the more difficult it will be to understand. Therefore, there will be a perception of greater risk and uncertainty of successful implementation.

- Divisibility and congruence – The more divisible an innovation is the more likely it is that partial adoption will occur. However, adoption will not occur if objectives appear to be indivisible and if farmers believe there is incompatibility with farm and personal objectives such as capital and income.

- Economics and capital outlay - Under the classical model of adoption, guaranteed greater economic returns from the innovation will encourage adoption. If, however, large capital outlay is required, or improved economic return cannot be guaranteed in a period of low income, farmers will wait until the innovation has been proved by others to be economically viable before adoption.

- Conflicting information and intellectual outlay – Most new technologies are subject to debate on their effectiveness, leading to the release of conflicting information. If the innovation requires changing skills and a greater knowledge base as well as the perceived uncertainty, this will lead to non-adoption.

- Social infrastructure (farming subculture) – In the farming community there tend to be 'accepted ways of doing things'. New ideas that move away from the 'traditional' approach and lead to greater constraints on the farmer's activities are less likely to be adopted unless there is consensus to adopt among the whole of the local farming community.

2.6.3 What lessons have been learned from the Australian approach?

The original aims of Landcare were set out to tackle serious environmental problems on a continental scale. Clearly there were considerable successes in motivating the rural community to act together but after 15 years did the programme achieve the desired success and if not, why not?

- Landcare requires the availability of profitable, practical, technically sound land management options – these are not always available, and if they are, the rural community is not willing to try untested ideas.

- It took far longer than anticipated to achieve ecologically sustainable resource use. Possible reasons for this include:

  - the original expectations were unrealistic;
  - there was confusion over who should pay for what;
  - the scale of the problem was far bigger than first envisaged, particularly in the Murray-Darling basin.

- Government Agriculture and Environment departments need to work more closely together to provide integrated approaches to programmes – 'community participation' and 'bottom-up' have provided a cover for transferring responsibility from government to community level but without commensurate resources.

- The National Landcare Program is too bureaucratic. In some cases as little as 14% of funding reaches the projects (Campbell, 1997).

- Landcare must be fully inclusive of all land holders – in Australia Aboriginal people only receive a fraction of Landcare funding but are significant landholders. More effort is required to bring small groups into the scheme.

- There is a need for more partnerships with industry to achieve ecologically sustainable resource use. Communities often lack knowledge of the status of water quality or the impacts of particular activities in their local area – some see this as a 'water insensitive culture' and there is a lack of social willingness for change.

- There can be a lack of technical capacity in the local facilitator or local government to undertake river health planning. Campbell (1997) argues that it may be better to appoint technical specialists who have been trained to improve their 'people skills'. However this type of facilitator needs to be aware of the quality of relationship required among group members – too much jargon can have a detrimental effect.

- There has been a gender bias. Women rarely are active members.

- Some groups have established 'group-rules' – e.g. a waiting list, or not missing more than three meetings. This may lead to elitism and exclusion.

Carr (1997), argues that Landcare will stagnate unless more attention is given to issues of participatory practice. Innovations in the process by which we learn, create, categorise and disseminate data are needed. Community groups need access to data and information in ways that do not rely on external sources of expertise. Some landholders think it is 'old games with new rules' and the 'group-think' mentality can stifle individual needs and diversity – some members will be more up-front whilst others are more passive.

2.6.4 Can a Landcare / facilitator / participatory approach be adopted in the UK?

Government agencies and departments often believe that the information the farming community has about water quality may be 'wrong', 'inaccurate' or 'incomplete' and that this may lead individuals to not having 'the full-picture' or all the 'necessary facts' to make a wise decision. This criticism is not entirely true; whilst some farmers may not know the 'full-picture', some certainly will be better informed than others. What is more likely to be true is that there is a lack of trust between the farming community and government organisations. Many farmers are sceptical about the motives and agenda of Government, believing that 'facts' can be presented in such a way that distorts the 'full-picture'. If there is to be real progress made in meeting the requirements of the WFD in the UK, then there is a need to foster partnerships between growers, processors, governments, private organisations, landholders and local urban communities to break down the barriers and encourage shared understanding, stimulating ideas and active learning and knowledge transfer. Whilst some of these partnerships may already exist it is essential that they become more meaningful, if mutual benefit is to be achieved in the coming decade.

In Australia, Landcare has been successful in attracting funding from large corporations for environmental projects (Landcare, 2003). For example, the Landcare website [14] describes the following partnerships: Alcoa World Alumina

[14] http://www.landcareaustralia.com.au

Australia is Landcare's strongest corporate partner, providing over A$17 million to Landcare projects since 1989; Banrock Station Wines, donates a proportion of its proceeds from every bottle or cask sold to Landcare Australia and Wetland Care Australia for wetland restoration projects around the country. Major hardware retailer, Mitre 10, joined forces with Landcare Australia in 2001 and has provided funding for waterway restoration projects across the country including the removal of willows, revegetation, riverbank stabilisation, the improvement of native wildlife habitat and wetlands restoration. This additional funding source has enabled hundreds of grants (most grant applications have a value of up to A$500) to be allocated across Australia, making this one of the most substantial and far-reaching educational programs ever undertaken.

In the UK, Government agencies and departments need to take on board these lessons from the Australian approach. There has to be a concerted effort to involve not only the Government's funding for large scale projects but also involvement from businesses and the wider community in funding projects that will improve aquatic ecosystems.

2.7 Perceptions and decision making studies

The continued problem of nitrate pollution in countries with highly mechanised, intensive agricultural systems has drawn attention to the need for greater integration of land management and water resources, and the involvement of stakeholders in all levels of decision making. Research into methods of encouraging public participation, particularly at the level of local actors (e.g. the farming community) indicates that management decisions that are made in collaboration with stakeholders are more effective and durable (Chess and Purcell, 1999; Collentine *et al.*, 2002; Jiggins, 2002; Johnson *et al.*, 2001). In recent years there has been a fundamental change in the accepted values, ideas and principles, which guide the behaviour of policy makers, planners and managers (Ducros and Watson, 2002). However, public participation in watershed management is far more developed in the United States, Australia and New Zealand. In the UK participation has tended to focus on public inquiries rather than management planning and decision making. Watson *et al* (1996) state:

> *"Integrated resources management involves the development of co-ordinated or linked arrangements for decision making with the aim of reducing resource conflicts and where necessary, resolving them".*
> (Watson *et al.*, 1996)

The Swedish study by (Eckerberg and Forsberg, 1996), found that successful implementation of policy instruments may be constrained by factors at the local level. In relation to farmers these factors are:

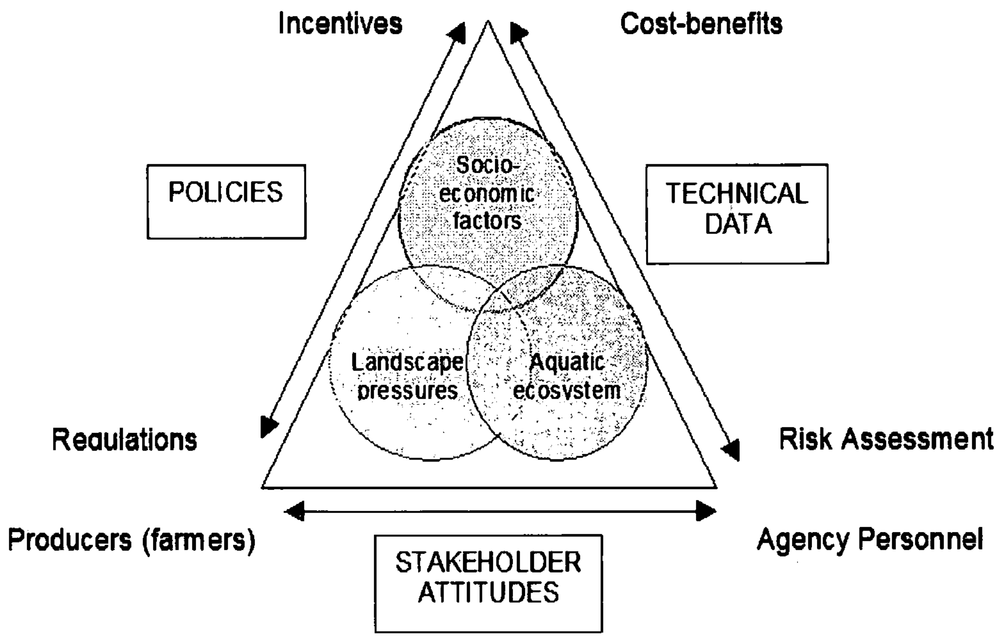
- How farmers perceive the policy problem;
- The level of consensus over who is to take responsibility for initiating changed behaviour;
- How economic and resource related consequences involved in such change should be borne.

For successful public participation, there needs to be more development of the collaborative/social learning processes especially in terms of :

- Understanding the problem situation;
- Defining desirable and/or feasible futures;
- Generating alternatives for action, enabling all to move in the direction;
- Developing action plans, implementing and evaluating the outcomes. (Collentine *et al.*, 2002).

However public participation is often criticised for not involving the full range of 'appropriate' stakeholders. Watershed and ecosystem management essentially involves the management of people from a range of different socio-economic backgrounds and their activities on the landscape (Brezonik *et al.*, 1999). Figure 2.9 below, illustrates the links between the desired relationships that should be encouraged in Integrated Catchment Management.

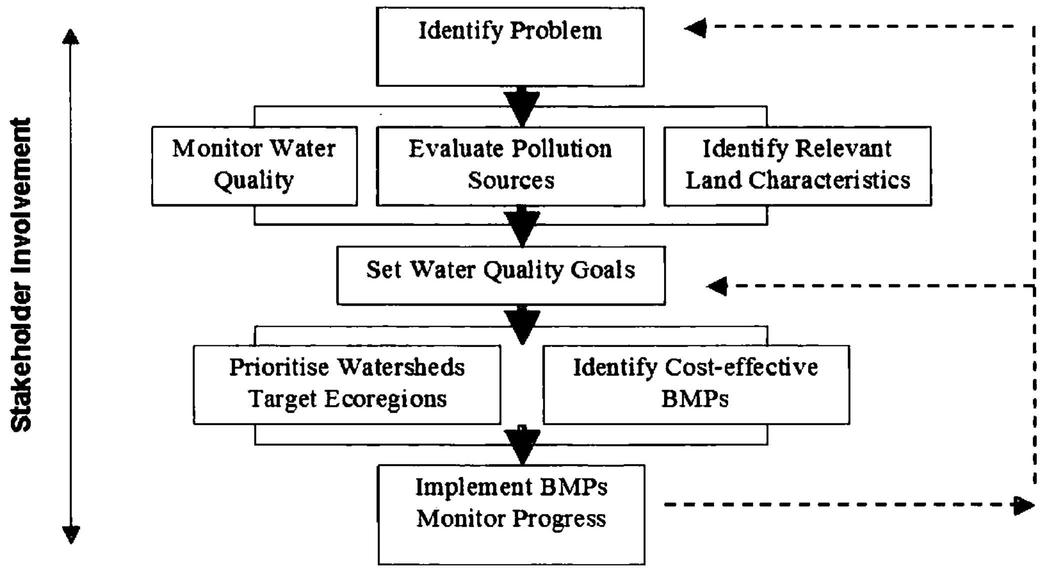
Figure 2.9 Desired relationships for Integrated Catchment Management



(adapted from Brezonik *et al*, 1999)

Brezonik *et al* (1999) go on to state that stakeholder involvement in the entire process is crucial and that a series of steps should be followed. Illustrated in figure 2.10 below, this framework includes steps whereby the problem is identified, then it is monitored and evaluated, and then goals and targets are set and implemented. However, the key in the management of these steps is that the process is on-going. Each step is re-visited as knowledge, attitudes and involvement of stakeholders' changes.

Figure 2.10 Framework for management of agricultural watersheds



Pretty (1996), argues that regenerative and low-input agriculture can be highly productive, provided farmers participate fully in all stages of technology development and extension; agriculture is as much a function of human capacity and ingenuity as it is of biological and physical processes. Sustainable agriculture seeks the integrated use of a wide range of pest, nutrient, soil and water management technologies.

Pretty goes on to say that modern models that promote sustainable agriculture require:

- Linear 'top-down' transfer of knowledge and technology;
- Participatory 'bottom-up' discussion groups;
- One-to-one advisory services;
- Structured education and training.

This is because:

The linear top-down approach builds on the ideas developed by Hagerstrand in the 1950s. these are based on his theory of innovation diffusion as a spatial process (Hagerstrand, 1967), and assumes that new agricultural technologies and knowledge are developed and validated by research scientists and it is the role of government agencies and advisors to promote the adoption of these technologies by farmers, thereby increasing productivity. Whilst 'early adopters' or 'progressive farmers' would be thirsty recipients of this knowledge, there has been a perception that farmers outside this group, who for one reason or another are slow to adopt new technology are 'laggards' that operate in an intellectual vacuum and would have to wait their turn as innovations diffuse down to the majority of producers (Race *et al.*, 2001). This theory has reinforced existing social inequalities within the farming community, as those who benefit most tend to have greater financial and capital resources and intellectual and social strength.

The participatory approach recognises that the farming community is rich in knowledge and practical skills and these are of great value with complex and untested enterprises. Groups that follow the participatory approach implicitly acknowledge the value of sharing ideas and information amongst themselves, rather than always relying on information and advice from government agencies. This approach allows members to take 'ownership' of both problems and solutions and in this way they can create viable farming systems adapted to the local context rather than implementing generic practices.

One-to-one advisory services can target key issues with expert advice. However, they are becoming more expensive to operate and small farmers find it prohibitively expensive to take advantage of such services. It is argued that governments should have a responsibility to contribute to the day-to-day running costs of one-to-one services.

Structured education and training that improves the knowledge base and enhance career prospects may be more popular as many older farmers are reluctant to undertake formal, long-term educational courses, such as those offered by universities.

In summing up this approach participatory schemes are most likely to succeed and be effective when they:

- Exist within a wider context of social, economic and environmental imperatives;
- Link information from a range of organisations that is credible, reliable and locally relevant;
- Follow an analysis of the target audiences context and information needs;
- Apply a mix of, and emphasis on, approaches most appropriate to the learning style of the target audience;
- Build on local expertise and institutions, rather than displacement;
- Accept that it is as much about listening, as it is to about providing information;
- Increase the accessibility to information that can easily be understood;
- Are reflective and adaptive – based on skilled monitoring and evaluation.

However, solving problems that are new experiences to the whole group may not be successful and may therefore be best dealt with by a combination of new and traditional models.

Participation calls for collective analysis. Groups can be very powerful when they function well, but it is not sufficient to put a group together in the same place at the same time and hope its members will make an effective team. There must be a commitment from government agencies to move away from a 'teaching' focus that implies the transfer of knowledge from someone who knows to someone who does not know ("we are the experts… this is what you should do") to a 'learning' focus. In essence learning should be less about what is learnt but how it is learned. In a participatory approach shared perceptions are essential for group action where ideas have to be exchanged, negotiated and tested. Underlying values are not presupposed, but are made explicit, encouraging members to questions procedures. Organisations concerned with participatory processes need to be decentralised, with an open multidisciplinarity, capable of responding to the needs of the farming community rather than adopting a didactic approach.

2.8 Summary

This chapter has demonstrated that nitrogen flux models are now reasonably well developed and there are many options from which to choose. The potential for riparian land and vegetation to act as a buffer zone for nutrient flux is also well understood. However, studies have not focused on the requirements and impacts of government policy that influence riparian land use in agricultural land use. Furthermore the ability to produce accurate land cover maps from remote sensing imagery for integration in land use decision-making still needs to be fully evaluated for its suitability in the UK. The literature on decision making and perception studies has shown that a top-down approach to adopting new ideas produces 'laggards' but that the integration of a bottom-up approach has much to offer the success of the river basin management planning process. Actively encouraging the participation of stakeholder groups in the development of guidelines will enable the requirements of EU policy to be more easily met.

Chapter Three:

Characteristics of the study area

3.1 Choice of study area

The choice of study area was in part determined by practical considerations. It was necessary to identify a site that had known water quality problems; had predominantly agricultural land use; was in a travelling distance from Durham that made it accessible within two hours by car; and of a size that made monitoring a representative number of sites within one day possible. These criteria would facilitate data collection such as water sampling and interviewing stakeholder groups. In addition a site was sought where historical data sets would be freely available to enable longer-term patterns of land use and water quality to be analysed. Strong links already existed with environmental organisations in the lower Tweed catchment and the Department of Geography. These include the Tweed Foundation, the Tweed Forum and SEPA. Early contact with these organisations identified the Leet Water catchment as meeting the above criteria and therefore a suitable site for the research. In addition the site was the subject of impending legislative change with the introduction of the NVZ Regulations. Finally, SEPA welcomed the opportunity for independent research in this catchment.

3.1.1 Location

The research area is a sub-catchment of the River Tweed in the borders of Scotland, see figure 3.1 below. The Leet Water catchment is approximately 114 km^2, comprising the Leet Water and Lambden Burn as the main drainage channels, with smaller tributary burns of Redlaw and Harcase on the upper Leet, the Thirlington and Laprig Burns on the Lambden, and Eccles Burn on the lower Leet. In addition, there are several smaller un-named watercourses draining the area. The Leet has its confluence with the River Tweed at Coldstream. The catchment is rural, with the majority of land use being agricultural. Settlements are small, the town of Coldstream being the largest with a population of about 1800 people. Smaller settlements include Swinton (population ~250) and Leitholm (population ~150) (1991 Census, GRO). Within the catchment there are 48 working farms ranging in size from 46 ha to ~2000 ha. These practise the main types of farming, specialist dairy, livestock, arable and mixed livestock with arable (figure 3.2 below).

3.1.2 Topography, soils and climate

Figure 3.3 illustrates the topography of the catchment. The higher land to the southwest rises to the highest point at Sweethope Hill (207m) and 201m at the source of the Lambden Burn. The Leet rises from a height of ~70m in the northeast near the village of Whitsome. The Leet's confluence with the Tweed at Coldstream is about ~10m above sea level. The landscape is undulating including many drumlins, orientated in a generally sw-ne direction, and controlling the main stem of the stream network (figure 3.1).

The predominant soils (figure 3.4) within the catchment are from the Whitsome Association (Bibby, 1982) developed on drifts derived from Lower Carboniferous sediments and basic lavas, Upper Old Red Sandstone and Silurian Greywackes. The drifts (figure 3.5), a result of Devensian glaciation, are principally clay or loam tills derived from a variety of rocks, but having shales and marls as major components. Coarser-textured materials on the higher ground to the west form a thin veneer over the till in some areas. The area is naturally fertile, but the subsoils are only slowly permeable and natural drainage is imperfect. In intervening hollows between the drumlin ridges, natural drainage is often poor. During the 1970s most of the catchment was subject to under-draining as part of land drainage schemes to improve agricultural productivity. On average 15 percent of the land is given over to pasture for sheep, cattle and dairy herds, but this is lower near the settlements. The principal arable crops grown include winter wheat, winter and spring barley, winter and spring oilseed rape, and spring oats. In addition there are small areas of potatoes and other horticultural vegetables. Apart from Coldstream the percentage of arable land use ranges from 40 to 80% in each of the sub-catchments.

The climate is cool and temperate. The Leet is the driest gauged sub-catchment in the Tweed basin. Long-term average annual rainfall is 652 mm, with average annual runoff of 236mm a runoff percentage of 36%. Annual, mean temperatures range from 1°C in January to 13°C in August (Institute of Hydrology, 1996).

Figure 3.1 Leet Water catchment – drainage pattern

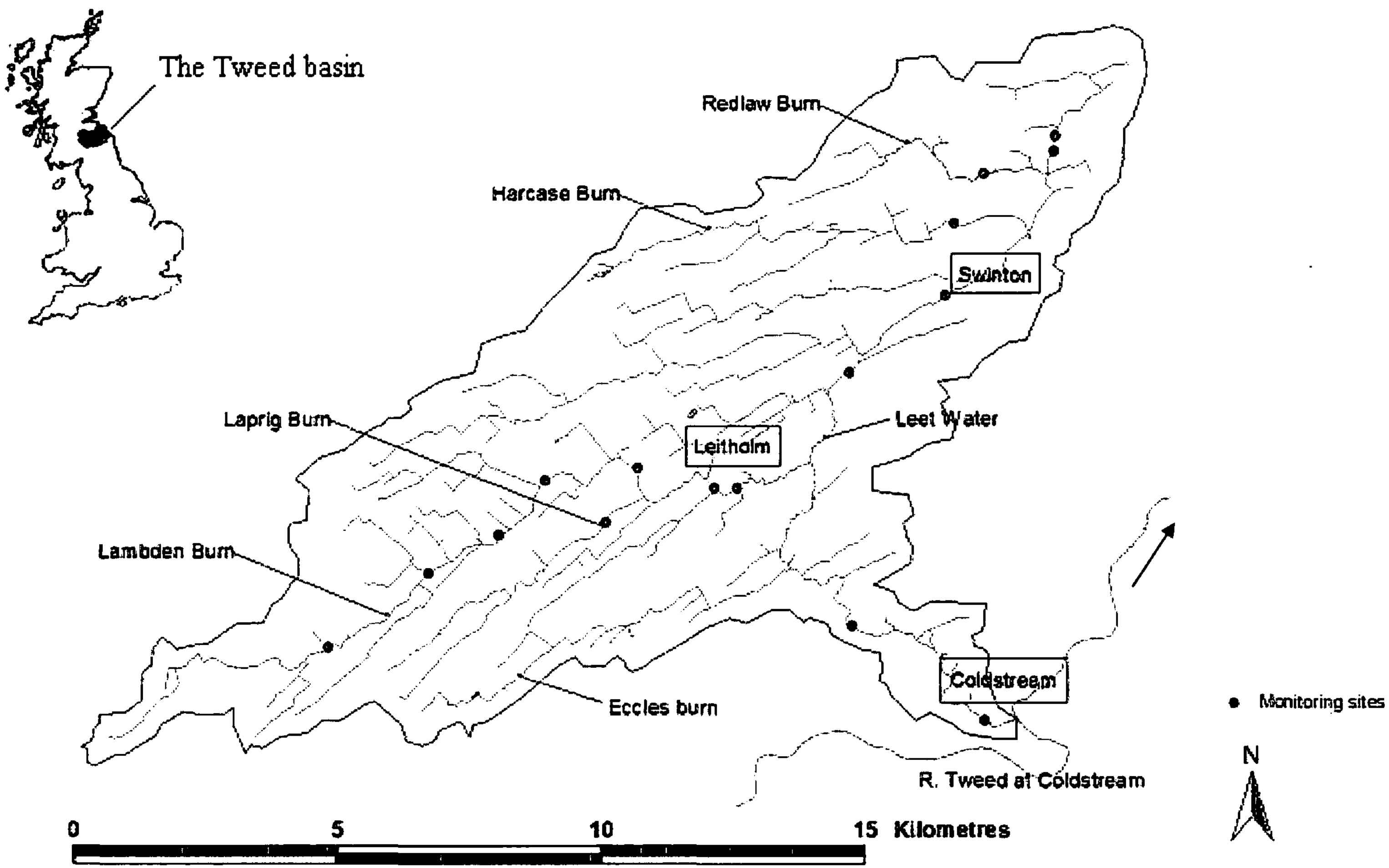


Figure 3. 2 Leet Water catchment – location of farms

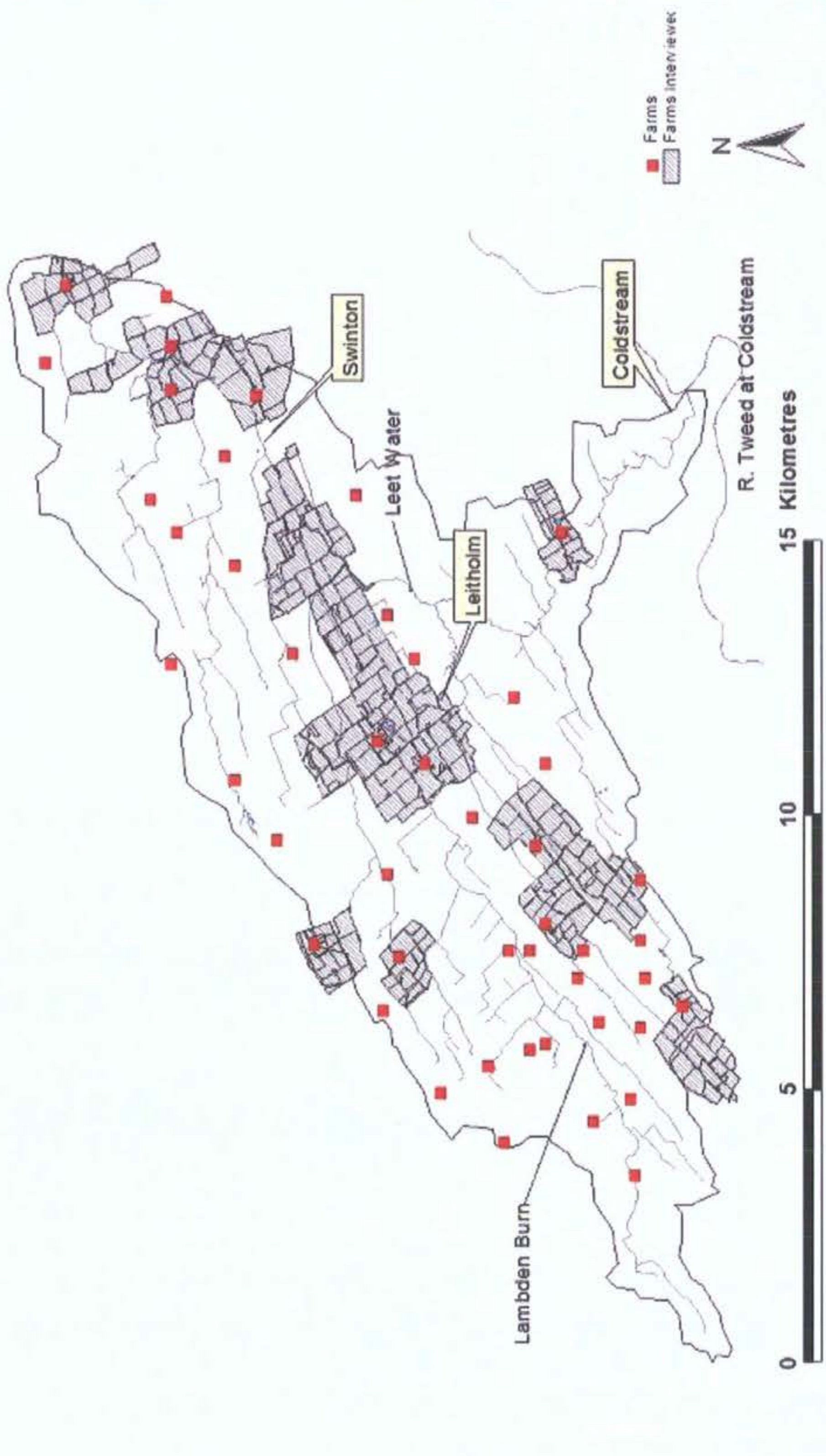


Figure 3.3 Leet Catchment topography and drainage

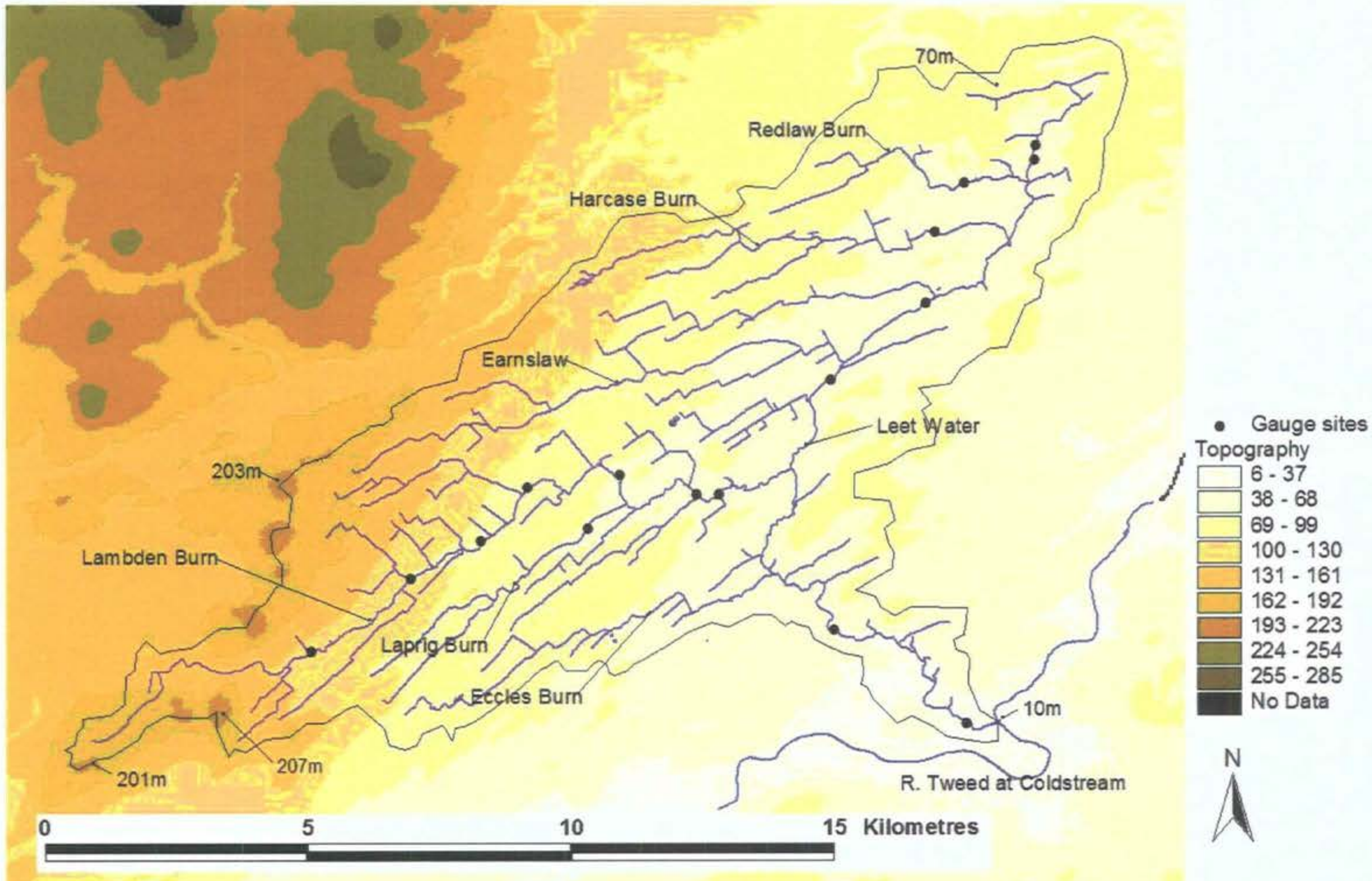
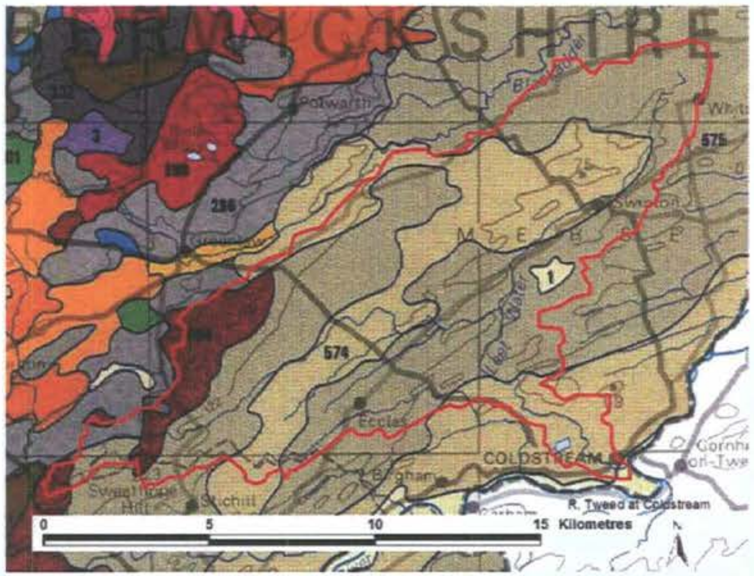


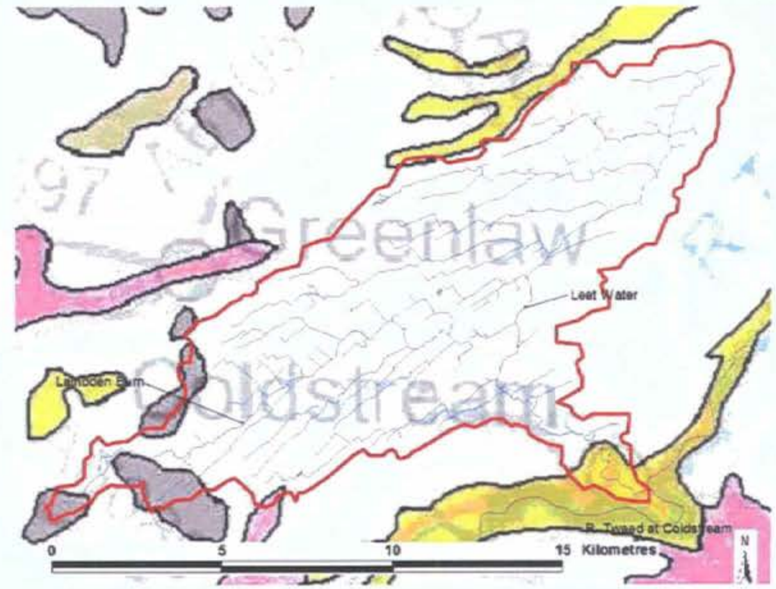
Figure 3.4 Leet Catchment soils



1	Alluvial Soils – recent riverine and lacustrine alluvial deposits
464	Smailholm – Drifts derived from L. Carboniferous basaltic lavas and U. Old Red Sandstone sediments (Brown forest soils)
574	Whitsome - Drift derived from L. Carboniferous sediments and basic lavas, U. Old Red Sandstones and Silurian greywackes (Brown forest soils with gleying, brown forest soils)
575	Whitsome - Drift derived from L. Carboniferous sediments and basic lavas, U. Old Red Sandstones and Silurian greywackes (Brown forest soils with gleying, some noncalcareous gleys)

Source: Soil Survey of Scotland Southeast Scotland 1:250000 (Sheet 7)(Bibby, 1982)

Figure 3.5 Leet Catchment surface geology



- Boulder clay & morainic drift
- Alluvium
- Glacial sand and gravel
- Peat
- River Terrace deposits

Source: British Geological Survey

3.1.3 Water quality

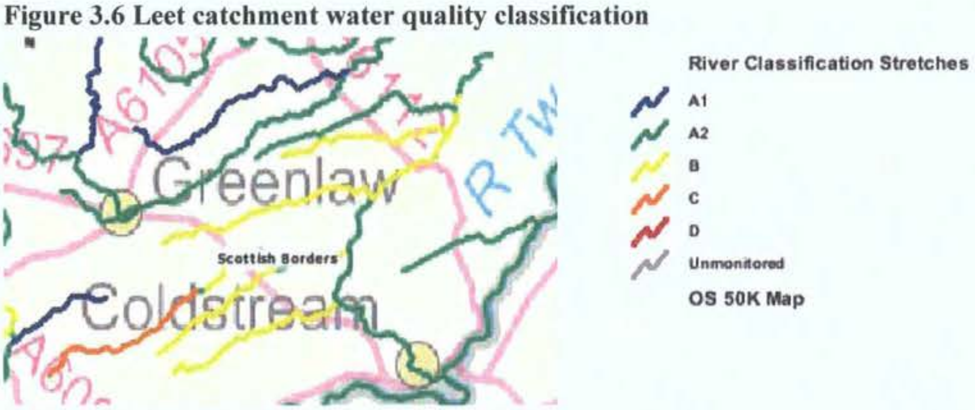
River water quality is classified by SEPA into one of six groups as shown in table 3.1 below.

Table 3.1 River water quality classification categories

Class	Description
A1	Excellent
A2	Good
B	Fair
C	Poor
D	Seriously Polluted
U	Unclassified
Source: SEPA 2002	

In the Tweed basin as a whole, 99% of the waters are Class A2 to A1 (good to excellent). However the Leet catchment varies from Class C (poor) to Class B (fair), with some sections A2 (good), see figure 3.6 below, due to its high nutrient load.

Figure 3.6 Leet catchment water quality classification



Source SEPA: http://www.sepa.org.uk/rqc/map.asp

High nitrate and phosphate concentrations have led to excessive growth and decomposition of weed in the eutrophic conditions. SEPA and its predecessor the Tweed River Purification Board, have monitored water quality across the Leet catchment with some data sets going back to 1960. Long-term concern about the level of nutrients in the watercourses has led SEPA to use a combination of persuasion and education with regard to potential inputs from agriculture. There is a small stakeholder forum in the catchment, The Leet Catchment Management Group, comprising members from the local farming community, SEPA, and other interested parties. This was set up to address the issue of water quality in the catchment, but it rarely meets and there is some confusion amongst the farming community as to its role in the group. Within the Tweed basin there are other organisations concerned with water quality and biodiversity (in particular, fisheries interests), including the Tweed Foundation[15] and the Tweed Forum[16]

3.2 Monitoring sites

3.2.1 Site selection

SEPA provided this research with long-term data sets from its monitoring programme within the Leet Water catchment. Water samples are usually collected between four and six times a year, to enable a comparison of the seasonal chemical profile of the water quality across the catchment. There is no set, regular interval between each measurement. Although some sites have longer time series data than others, there is generally an excellent data set from 1986 – 1997 for 16 sites.

However, financial cutbacks within the SEPA monitoring programme meant that a reduced number of sites were monitored after 1997, and at a less frequent interval. To bring the data set up to date during the research period, flow measurements and water samples have been collected across the catchment (including the SEPA sites) and analysed in the Durham University Geography Department laboratories using a Dionex ion chromatograph. Due to time and travel constraints, there was no set time interval between data gathering and access problems sometimes made it impossible to monitor all sites. A best attempt was made to collect samples weekly over the winter months of 2002/2003, reducing to fortnightly, then monthly during the summer months. This enabled continuation of the data set through to August 2004, and first-hand observation and photographic recording of management practices at each sampling point throughout the study period.

[15]http:// www.tweedfoundation.org.uk
[16]http:// www.tweedforum.com

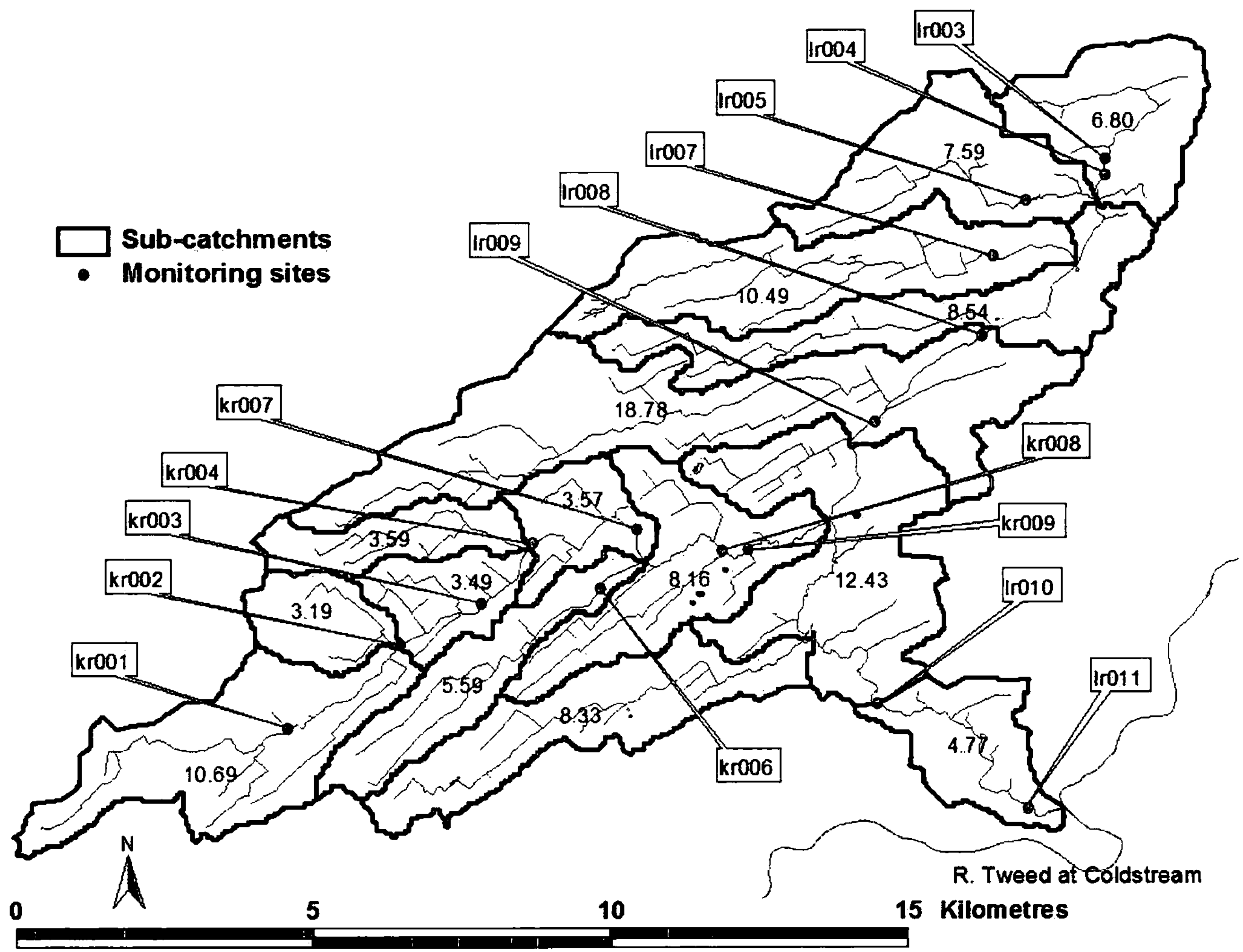
3.2.2 Site characteristics

The following pages illustrate the characteristics of each monitoring site. The area contributing to each site is treated as a sub-catchment to enable a comparison of its area, drainage characteristics, land use and water quality. Long-term NO_3-N data have been included to indicate the historic seasonal trend of NO_3-N concentrations and to put the water quality problem of this catchment in context. A red line on each graph indicates the 11.3 mg/l permitted maximum of NO_3-N for illustrative purposes. Calculations for the extent of each sub-catchment (figure 3.7) and length of drainage network were carried out in ArcGIS 8.3 using a Digital Elevation Model (DEM) derived from OS Panorama and OS Landline data from Digimap (http://www.edina.ac.uk). Land cover information at the field scale was derived from aerial photographs for the 2002 growing season and ground surveys during 2003 and 2004. These data were firstly classified into specific crop type and then amalgamated into six land cover classes, including arable, pasture (fertilised and unfertilised), set-aside, woodland, and urban. For brevity, only percentages for arable and pasture are included in the comparison as these are the two land cover types that require additional natural and artificial fertiliser.

3.2.3 Long term NO_3-N trends

From the graphs, the long-term NO_3-N data indicate three similar patterns at all sites. Firstly, there is an annual cycle. NO_3-N concentrations are low during the summer months indicating uptake of nutrients during the growing season, then rise during the winter months following wetting up of the soil and leaching of nitrate. This could be residual nitrate, but might also be recently mineralised in warm re-wet (autumn) soils. Secondly, from 1990 there is a general increase in the winter concentration of leached NO_3-N. This reflects a period of growth in agricultural output on farms due to increasing fertiliser applications – a result of EU farm support payments under the Common Agricultural Policy (CAP). Thirdly, it is from this time that there is an increase in number of occasions that the 11.3 mg/l limit is exceeded. However, it is not clear whether the lack of a clear annual cycle prior to 1989 is a real effect or an artefact of the data. In particular, it is not known if sample storage and analysis was changed from 1989 onwards.

Figure 3.7 Areas (km^2) of sub-catchments



3.2.4 Lambden Burn sites

Sites KR001 and KR002 (figures 3.8 and 3.9) are the furthest upstream on the Lambden Burn. Here the stream channel has undergone little modification. Width and depth generally vary little, generally being less than 20cm deep, but width can swell from approximately 1m up to 3.5m under high rainfall conditions, when flow responds rapidly. Flow is usually 0.09 – 0.5m^3s^{-1}, but can rise to 0.78 m^3s^{-1} after heavy rain. The land adjacent to the watercourses tends to be pasture and heavily grazed by cattle in the summer months and sheep the rest of the year. There has been limited fencing to the watercourses in these two sub-catchments and this exacerbates water quality problems by cattle poaching (enter the stream and excrete waste) the stream. At KR001 there have been few occasions on which the NO_3-N 11.3mg/l limit has been exceeded, but at KR002 there have been seven occurrences since 1990, including three major events when NO_3-N was >15 mg/l.

At KR003 (figure 3.10) the Burn is wider but very shallow, ranging from 1.5 to ~3.5m wide and 10 to 42cm deep. Vertical banks are approximately 0.75m high. The streambed is in a poor state, littered with several items of agricultural rubbish. Adjacent arable land is ploughed to within 2m of the watercourse and is prone to flooding with rapid runoff increasing soil and NO_3-N inputs to the stream. Winter NO_3-N inputs are often close to and exceed the 11.3 mg/l limit.

Between sites KR003 and KR004 modification of the stream channel is very apparent. The banks were straightened and deepened (probably during the 1970s) to accommodate drainage from the construction of field drains. Land use directly adjacent to the KR004 site (figure 3.11) is in a poor condition, being a disused section of road and bridge. The old road is now hard standing and appears to be used as a dump for derelict vehicles by a local contractor and also by the local authority for materials for road improvements. Up-stream of the old bridge the channel ranges from 1.38 to 4.25m wide and from 13 to 64cm deep. Down-stream the straightened, narrow channel (including a culvert) has meant this section of stream rapidly overflows its banks during periods of wet weather increasing the potential for nutrient leaching and soil erosion. Field drains from arable and pasture land discharge water direct to the stream, which contributes to the high concentrations of

NO_3-N during the winter months. There has been some attempt to plant woodland but this is much neglected, and vegetation overgrowth is a problem during the summer months.

As flow continues down-stream, water quality at the remaining sites on the Lambden deteriorates significantly. Data from KR006, 007, 008 and 009 (figures 3.12, 3.13, 3.14 and 3.15) indicate that every winter since 1990 the 11.3 mg/l limit has been exceeded, with 1996 and 1997 NO_3-N concentrations being particularly high. Arable land use at these four sites is more than 70% of the catchment area.

Land management at KR 006 makes a significant contribution to the water quality problem. Adjacent fields are under-drained and ploughed to within 2 metres of the water-course. Previously the field on the left bank had been used for livestock and an access point to the water-course is still a major source of soil erosion and run-off during wet weather. The volume of water is generally small, the width usually less than 1m and the depth only a few centimetres. During the summer months the stream dries up completely and this could account for the very low summer NO_3-N concentrations. However, due to deepening of the channel when the field drains were installed, flow can increase rapidly during heavy rain and the channel breaks its banks causing flooding of the adjacent fields. The farmer has recently increased the width of the permanently vegetated strip, but the old livestock access point has not been repaired and this would need to be built up to protect the watercourse from future erosion.

At KR007 the stream channel is much wider, ranging from 1.65 under low flow conditions but up to 6m after heavy rain. Depth is shallow varying from 7cm to 80cm. Here the profile of the water course returns to a more natural state. Upstream, established broadleaved vegetation and wider un-cultivated strips attempt to protect the watercourse. Although fencing protects the watercourse from livestock grazing, the fields continue to be underdrained, discharging water directly to the stream.

The Lambden Burn at KR008 has particular problems. The channel is deeper than all other sites upstream, depth was measured at 1.53m during one winter visit, but during the summer months depth can be as little as 37cm. Velocity can be very slow and on several occasions it was difficult to measure the rate of flow. During the summer months, the channel becomes very overgrown with vegetation and open water becomes covered in algal scum. Until very recently all sections of the stream bank were unfenced and livestock grazed the adjacent fields all year round. To exacerbate the problem a small sewage treatment works associated with the village of Leitholm is very close by, although SEPA is of the opinion this is not the cause of poor water quality.

KR009, is the furthest downstream sampling point before the Lambden Burn joins the Leet. The stream is at its widest and deepest, being 51cm deep and more than 4m wide. This site suffers from vegetation overgrowth, in particular reeds and algae during the summer months. This site was only sampled once throughout the research period due to access problems (significant building works and stored machinery blocked off the whole area). Previously, both sides of the burn were grazed intensively.

Figure 3.8 Site characteristics at KR001

Lambden below Hume Hall

OS Grid Ref: 371460 640940

Area: 10.69 km^2

Arable: 59%

Pasture: 27%

Reach length: 5400m

Min / max width (m): 0.70 – 2.42

Min / max depth (m): 0.11 – 0.38

Min / max velocity (m^3s^{-1}): 0.009 – 0.780

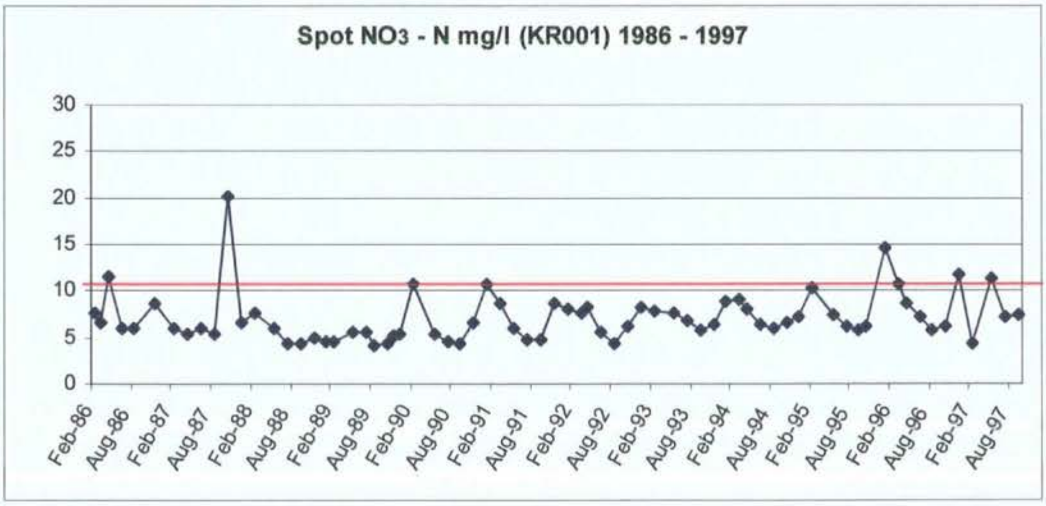


Figure 3.9 Site characteristics at KR002
Lambden at Stonefold Brae

OS Grid Ref: 374370 642900

Area: 3.19 km^2

Arable 72%

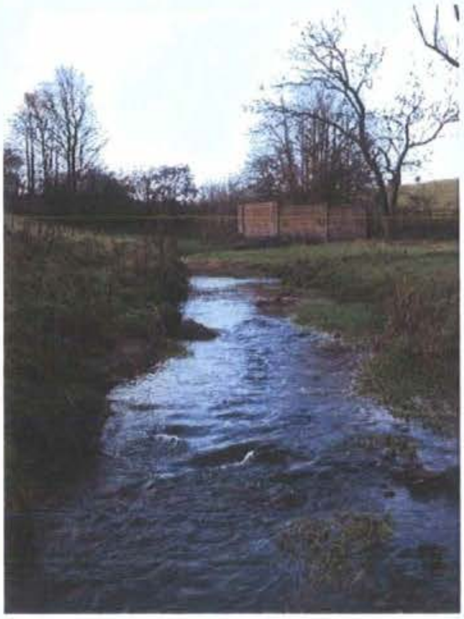
Pasture 11%

Reach length: 4800 m

Min / max width (m): 1.3 – 3.53

Min / max depth (m): 0.17 – 0.48

Min / max velocity (m^3s^{-1}) 0.047 – 0.549



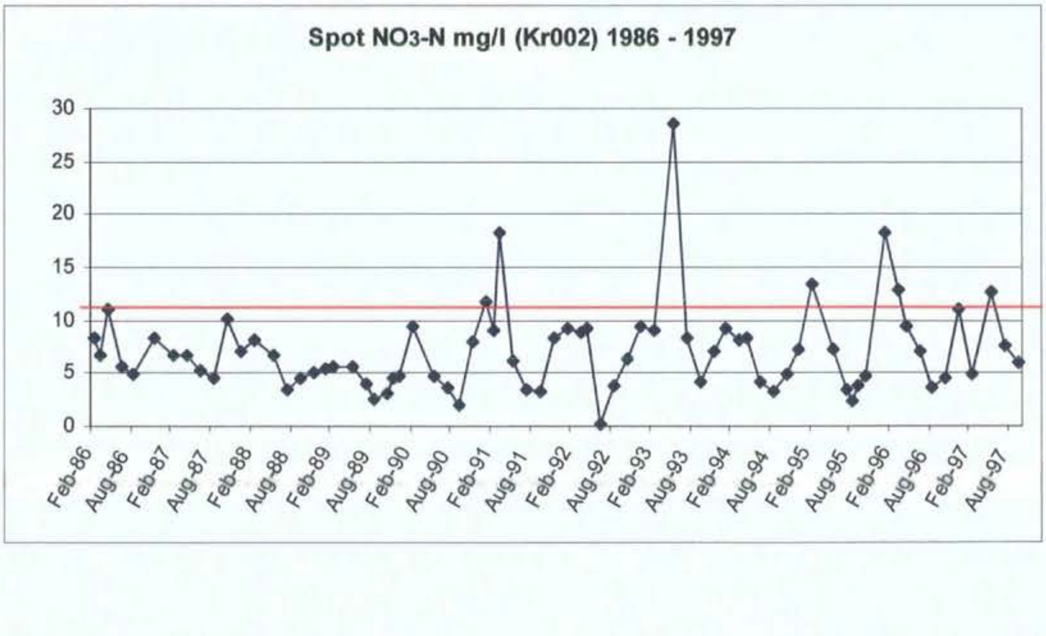


Figure 3.10 Site characteristics at KR003

Lambden at Lambden Farm

OS Grid Ref: 374700 643020

Area: 3.49 km^2

Arable 74%

Pasture 17%

Reach length: 1630 m

Min / max width (m): 1.5 – 3.53

Min / max depth (m): 0.10 – 0.42

Min / max velocity (m^3s^{-1}): 0.018 – 0.888

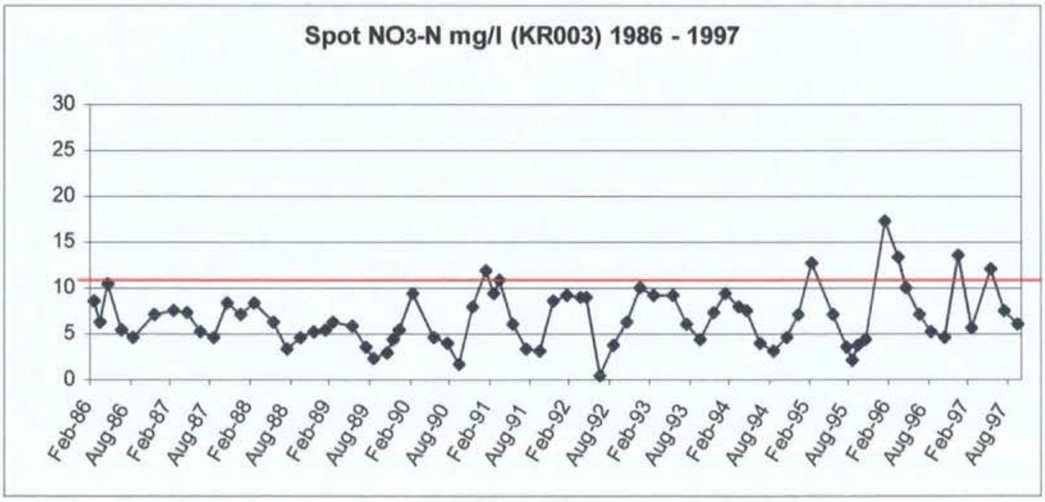


Figure 3.11 Site characteristics at KR004

Lambden at Ploughlands Bridge

OS Grid Ref: 375570 644040

Area: 3.59 km^2

Arable 80%

Pasture 7%

Reach length: 1400 m

Min / max width (m): 1.38 – 4.25

Min / max depth (m): 0.13 – 0.64

Min / max velocity (m^3s^{-1}): 0.014 – 1.233

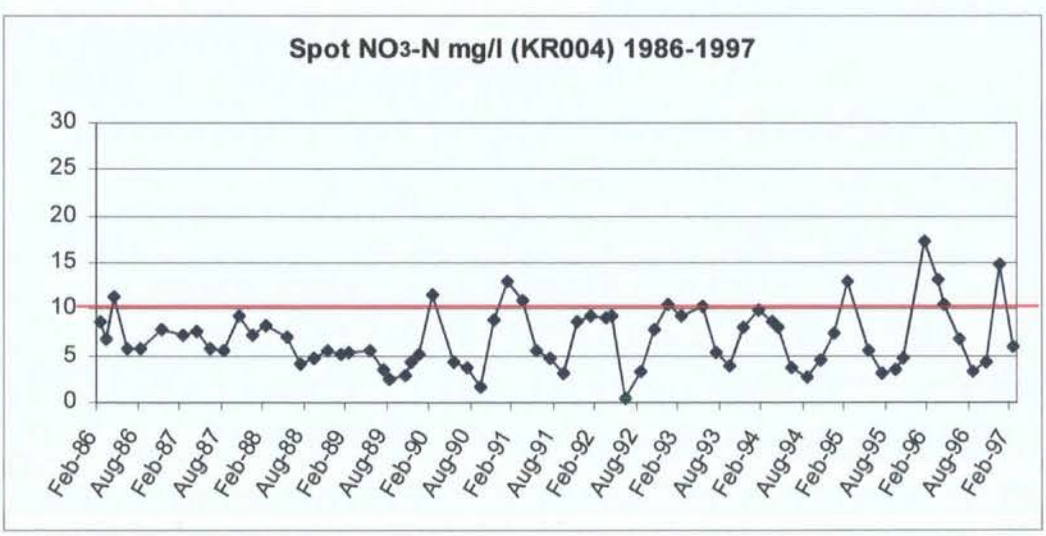


Figure 3.12 Site characteristics at KR006
Lambden at Springwells
OS Grid Ref: 376700 643270

Area: 5.59 km^2
Arable 76%
Pasture 21%

Reach length: 5310 m

Min / max width (m): 0 – 3.04
Min / max depth (m): 0 – 0.52
Min / max velocity (m^3s^{-1}): 0 – 0.685

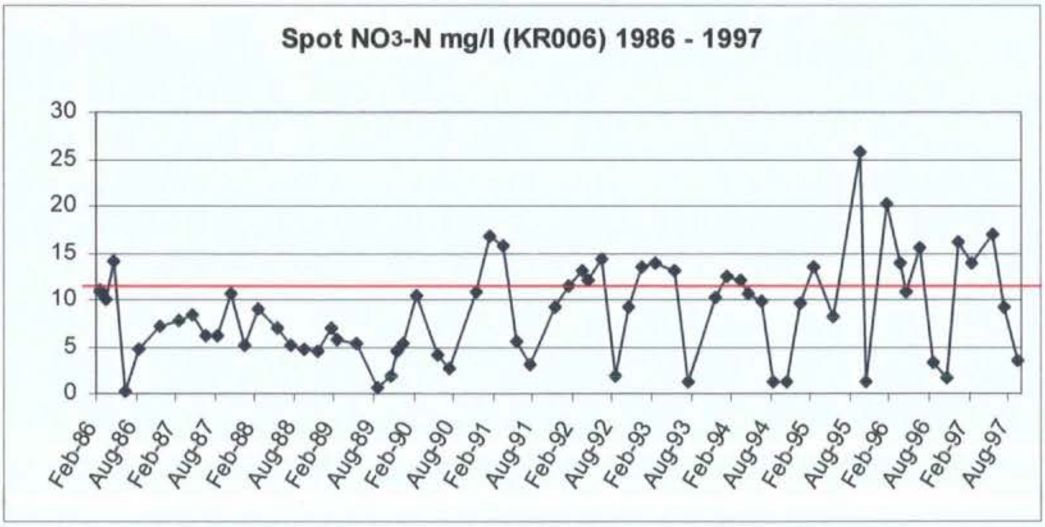


Figure 3.13 Site characteristics at KR007
Lambden at Mersington Farm
OS Grid Ref: 378600 643970

Area: 3.57 km^2
Arable 80%
Pasture 12%
Reach length: 2270 m

Min / max width (m): 1.65 – 6.0
Min / max depth (m): 0.07 – 0.80
Min / max velocity (m^3s^{-1}): 0.017 – 0.795

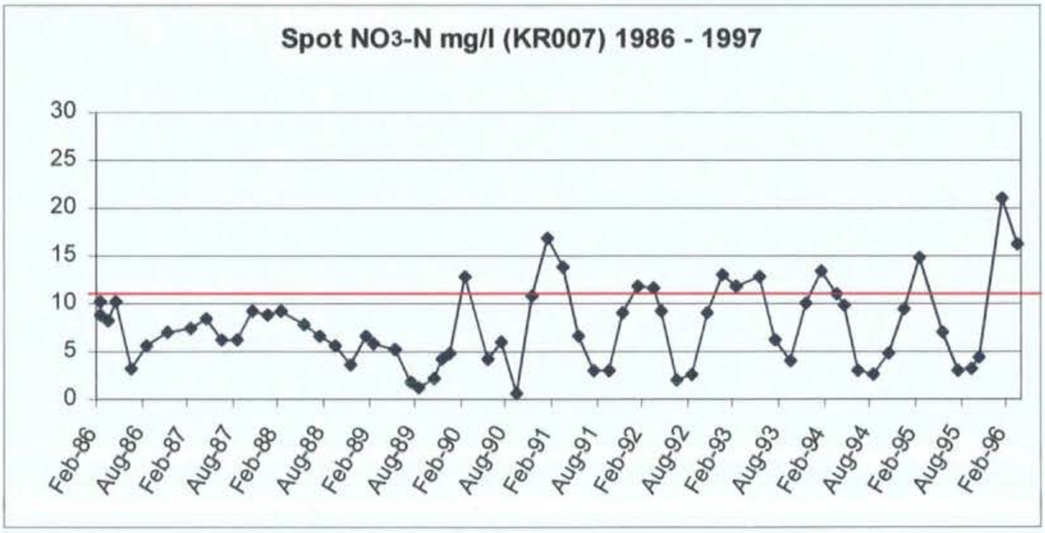


Figure 3.14 Site characteristics at KR008
Lambden at Leitholm Bridge
OS Grid Ref: 378700 643970

Area: 8.16 km^2
Arable 70%
Pasture 22%

Reach length: 2340 m

Min / max width (m): 2.08 – 4.25
Min / max depth (m): 0.37 – 1.53
Min / max velocity (m^3s^{-1}): 0.081 – 2.091

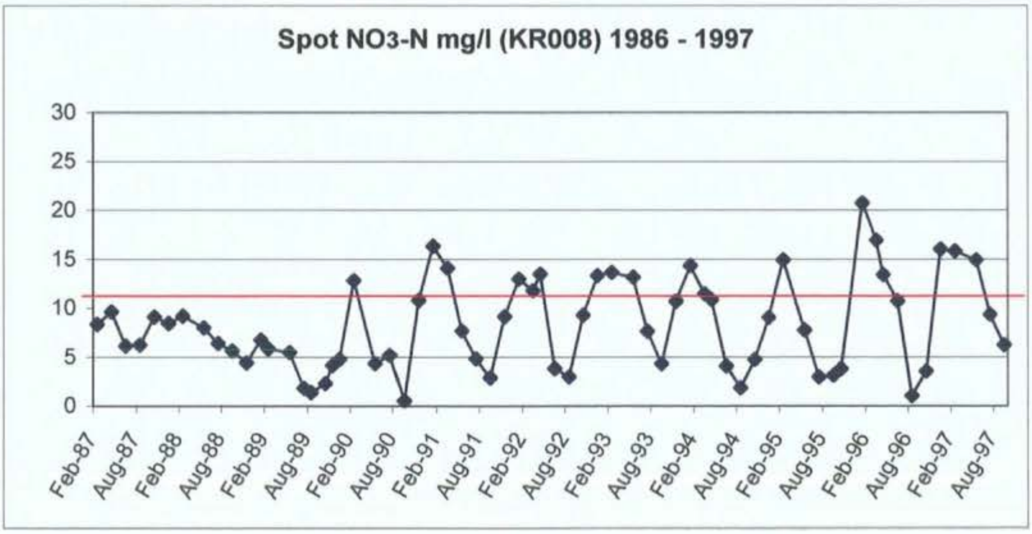


Figure 3.15 Site characteristics at KR009

Lambden below Leitholm

OS Grid Ref: 379200 643920

Area: combined with KR008

Arable 70%

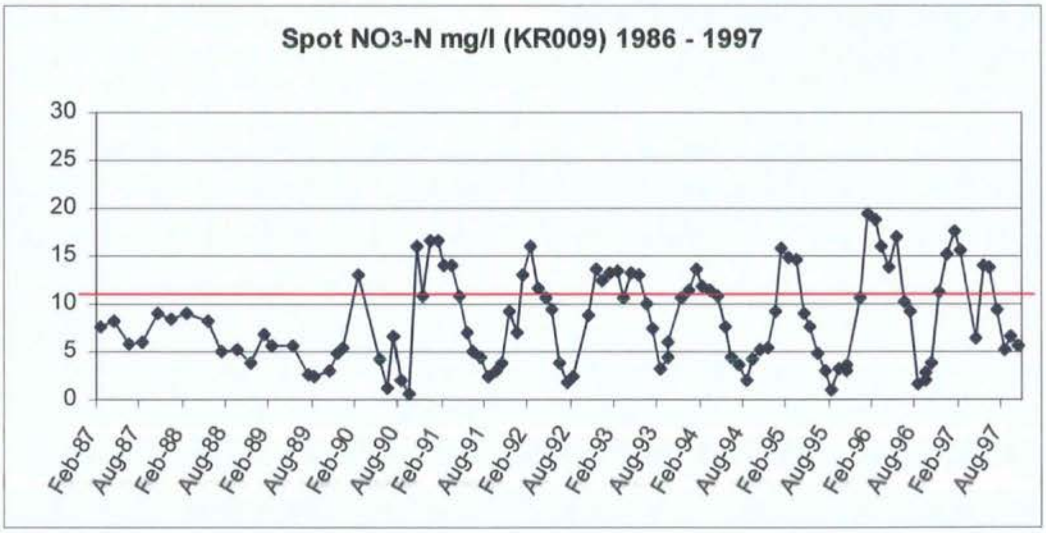
Pasture 22%

Reach length: 500 m

Width (m): 4.05

Depth (m): 0.51

Velocity (m^3s^{-1}): 0.24



3.2.5 Leet Water monitoring sites

The three sampling points at the top of the Leet catchment, LR003, LR004, and LR005 (Figures 3.16, 3.17 and 3.18) have similar characteristics. Along these three reaches the stream channel is very narrow, usually less than 1m wide. The depth of water is shallow, measurements recording depths ranging from 2cm in summer to 64cm after a period of heavy rain. The channel sides are particularly steep having been significantly modified to accommodate field drains. Arable land accounts for 55 – 59% of land use, with pasture between 14 – 21%. Generally water quality is better than has been recorded at the other sites. However, one significant exceedence of 11.3mg/l NO_3-N limit at LR003 in 1995 incurred a visit from SEPA who successfully used the incident to demonstrate the need for better land management practices in the catchment.

LR004 is of particular interest. It is adjacent to a small sewage treatment works (STW), serving the village of Whitsome and has been the subject of experimental works to improve water quality. SEPA chose this site to trial reed beds as a means of removing nutrients from waters leaving the STW. This is one site where winter concentrations of NO_3-N have been decreasing. However, access to the stream channel is very difficult as the reed bed needs to be negotiated, and then the banks become very overgrown with nettles and brambles which can cause injury whilst collecting samples. Generally, depth of water ranges from 4cm to 43cm with width ranging from 60cm to 3.9m.

The channel at LR005 (figure 3.18) on the Redlaw Burn has also been modified. Width varies from 1.10m to 3.85m, and depth was measured at 11cm to 62cm. On the right bank is a small conifer plantation and there have been some land management changes to the field on the left bank. Until recently this was an area of unfenced arable land, but during 2004 the field was fenced off with a buffer of 5m and converted to grazing for cattle.

The sites downstream including LR007, LR008 and LR009 (figures 3.19, 3.20 and 3.21) demonstrate the extent of modification the Leet has undergone. Rather than a natural water-course, the channel appears to be an enlarged trapezoidal drainage ditch. Summer flow is much reduced, with depth as little as 3cm, and width often less than 1m. The banks and channels become very overgrown with vegetation including brambles, nettles and weed during the summer. Water quality problems at LR007 have been exacerbated by the presence of a poultry farm. Food residues and dust from the poultry shed accumulate on the steadings and these run off into the watercourse during wet weather. The NO_3-N data indicate the 11.3 mg/l limit has been exceeded every winter since 1990. During 2003, a retention pond was constructed between the poultry farm and watercourse to intercept runoff from the steadings in an attempt to reduce nitrate levels in the water-course. It was not possible to record measurements at LR009 during the study period as access, via a very steep slope had been securely fenced off as it was adjacent to a very busy road.

The site LR010 at Charterpath Bridge (figure 3.22) has the longest record of monitored data. Water quality is poor, the NO_3-N limit being exceeded every winter. The channel at this site is broader but shallower than other sites being as much 8.8m wide, but only 10 to 71cm deep. Downstream of the bridge the field on the right bank is prone to flooding. To reduce the flooding effects, a levee has been constructed upstream of the bridge. However, the levee concentrates flow during heavy rain and following the serious flooding of 2002, the bridge structure was weakened. Water quality is poor at this site and is exacerbated by livestock grazing in the unfenced fields adjacent to the watercourse. During the summer months flow is reduced. Algal scum accumulates on the shallow water and the channel becomes clogged with weed and vegetation.

The lowest site downstream is LR011 (figure 3.23), and again the NO_3-N 11.3 mg/l limit is exceeded every winter. The Leet here is flowing through the town of Coldstream close to its confluence with the River Tweed. Beneath the modern bridge the channel ranges between 2.8 and 7.35m with a depth 7 to 27cm, but the channel has been narrowed and built up and protected with gabions to contain the flow, and depth is normally ~1m at the footbridge.

Figure 3.16 Site characteristics at LR003

Leet below Ravelaw Farm

OS Grid Ref: 385200 650450

Area: 6.80 km^2

Arable: 59%

Pasture: 21%

Reach length: 6900m

Min / max width (m): 0.60 – 3.80

Min / max depth (m): 0.03 – 0.36

Min / max velocity (m^3s^{-1}): 0.001 – 0.857

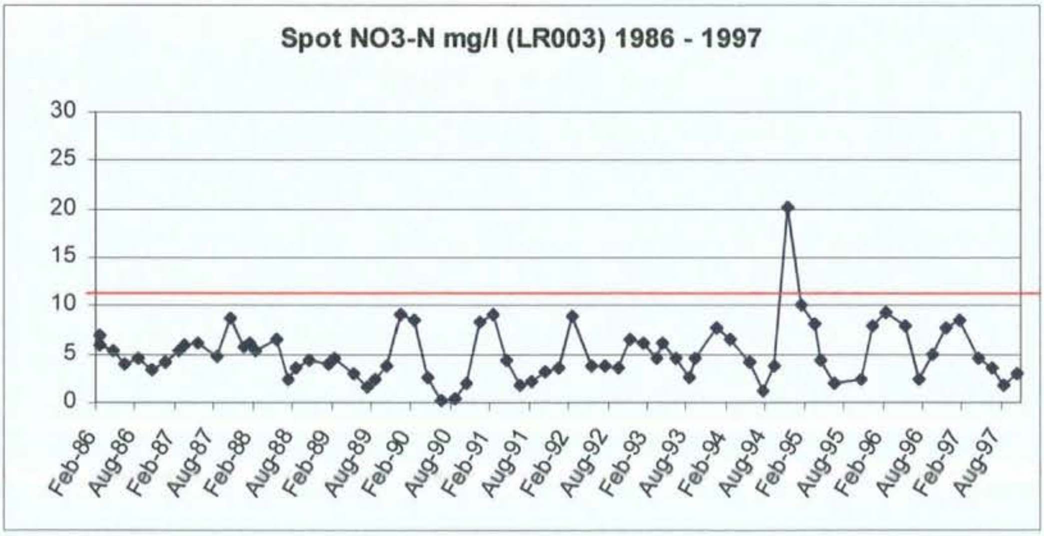


Figure 3.17 Site characteristics at LR004

Leet at Whitsome STW

OS Grid Ref: 385080 649800

Area: Combined with LR 003

Reach length: Combined with LR003

Min / max width (m): 0.60 – 3.9

Min / max depth (m): 0.04 – 0.43

Min / max velocity (m^3s^{-1}): 0.001 – 0.184

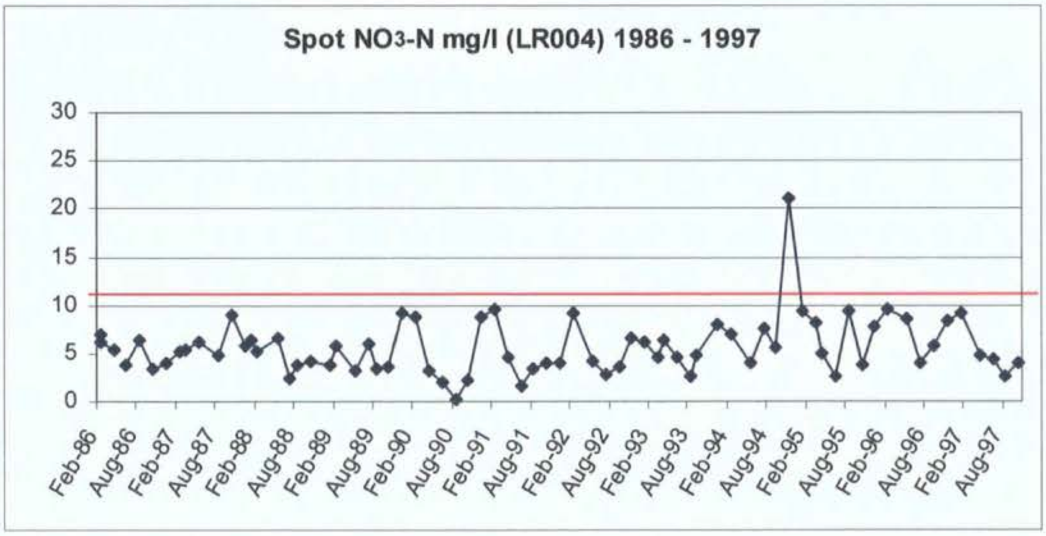


Figure 3.18 Site characteristics at LR005

Leet at Redlaw Burn Foot

OS Grid Ref: 385060 649740

Area: 7.59 km^2

Arable: 55%

Pasture: 12%

Reach length: 6900m

Min / max width (m): 1.10 – 3.85

Min / max depth (m): 0.11 – 0.62

Min / max velocity (m^3s^{-1}): 0.009 – 0.814

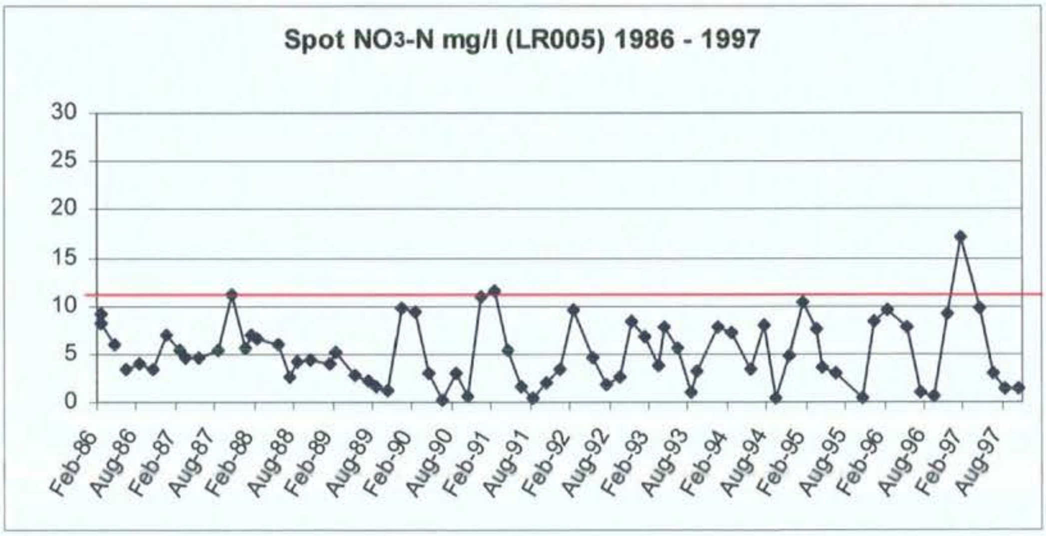


Figure 3.19 Site characteristics at LR007

Leet at Harcase Burn Foot

OS Grid Ref: 385060 648700

Area: 10.49 km^2

Arable: 50%

Pasture: 11%

Reach length: 15200m

Min / max width (m): 0.65 – 3.37

Min / max depth (m): 0.11 – 0.64

Min / max velocity (m^3s^{-1}): 0.001 – 0.944

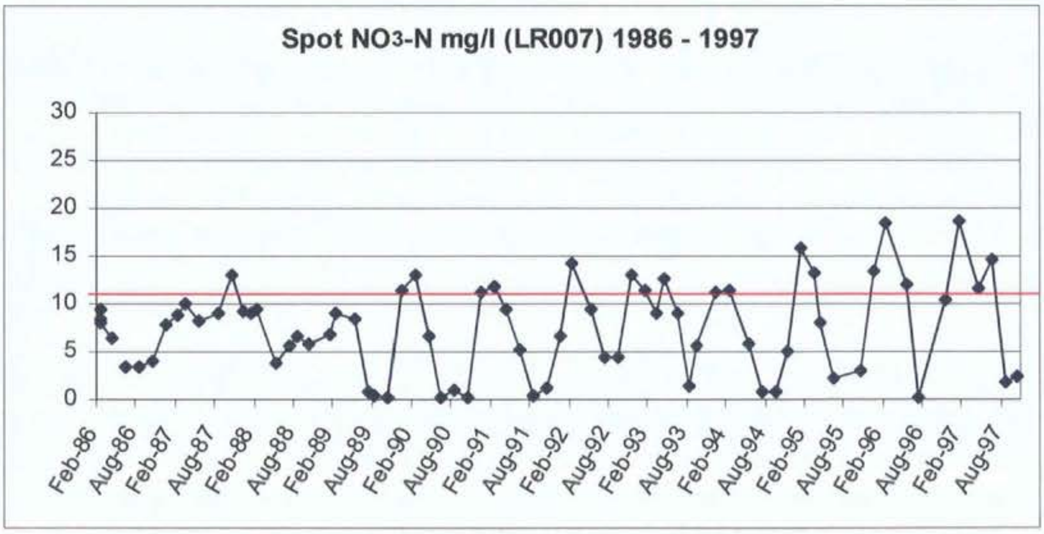


Figure 3.20 Site characteristics at LR008

Leet at Swinton Bridge

OS Grid Ref: 383120 647500

Area: 8.54 km^2

Arable: 45%

Pasture: 6%

Reach length: 10900m

Min / max width (m): 0.75 – 6.9

Min / max depth (m): 0.03 – 0.89

Min / max velocity (m^3s^{-1}): 0.001 – 0.980

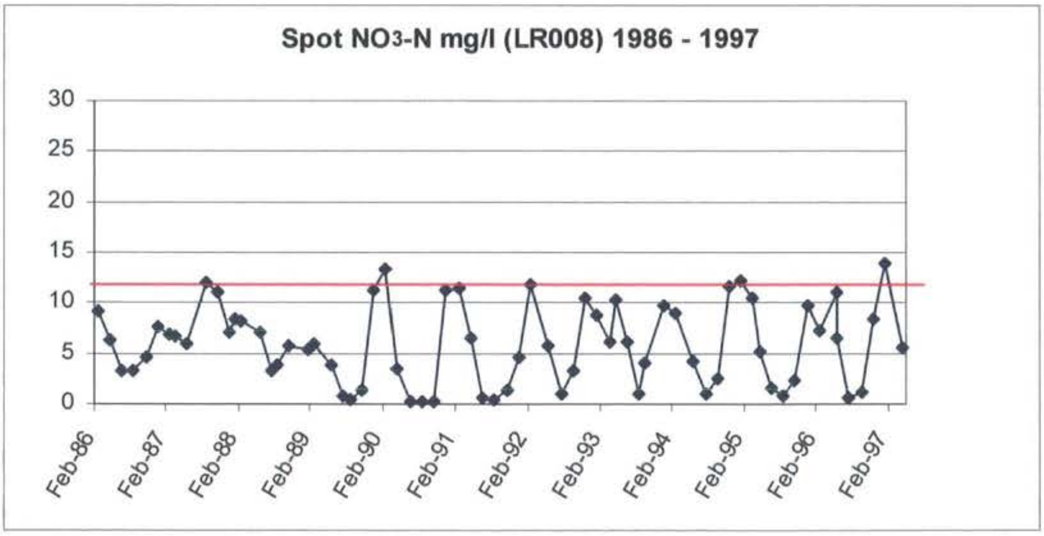


Figure 3.21 Site characteristics at LR009
Leet at Swintonmill

OS Grid Ref: 383150 647400

Area: 18.78 km^2

Arable: 41%

Pasture: 10%

Reach length: 20200

Min / max width (m): *not measured*

Min / max depth (m): *not measured*

Min / max velocity (m^3s^{-1}): *not measured*

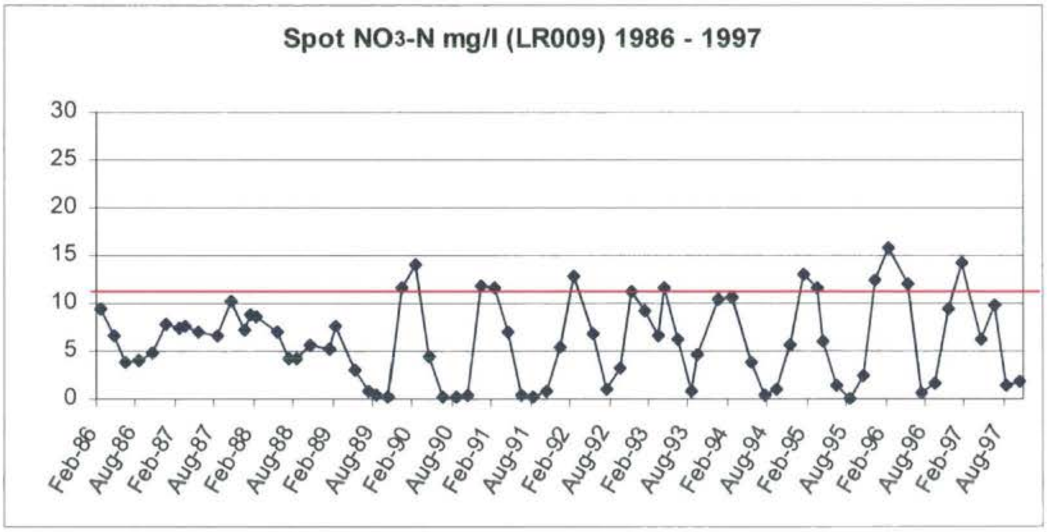


Figure 3.22 Site characteristics at LR010

Leet at Charterpath Bridge

OS Grid Ref: 381380 641350

Area: 12.43 km^2

Arable 60%

Pasture 13%

Reach length: 6500 m

Min / max width (m): 2.98 – 8.8

Min / max depth (m): 0.10 – 0.71

Min / max velocity (m^3s^{-1}): 0.025 – 3.713

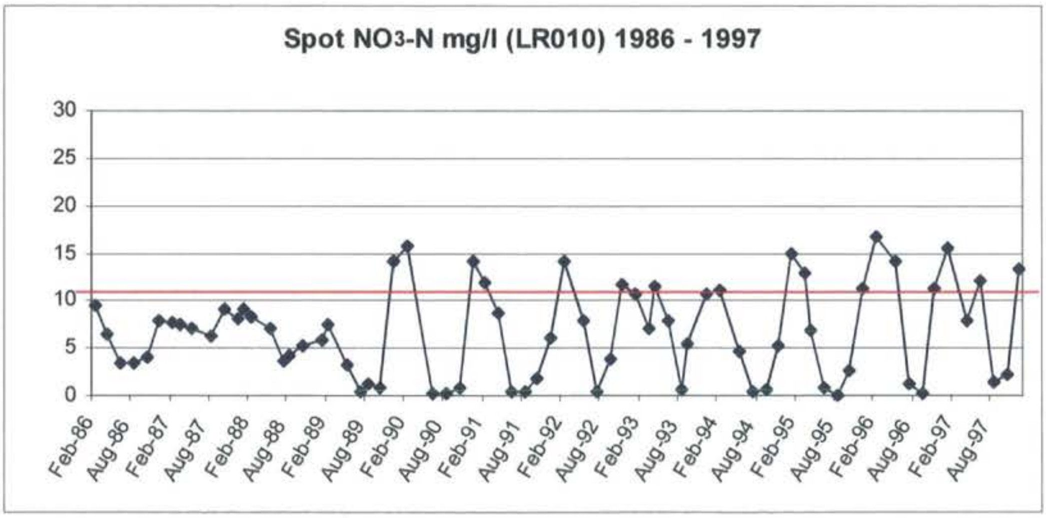
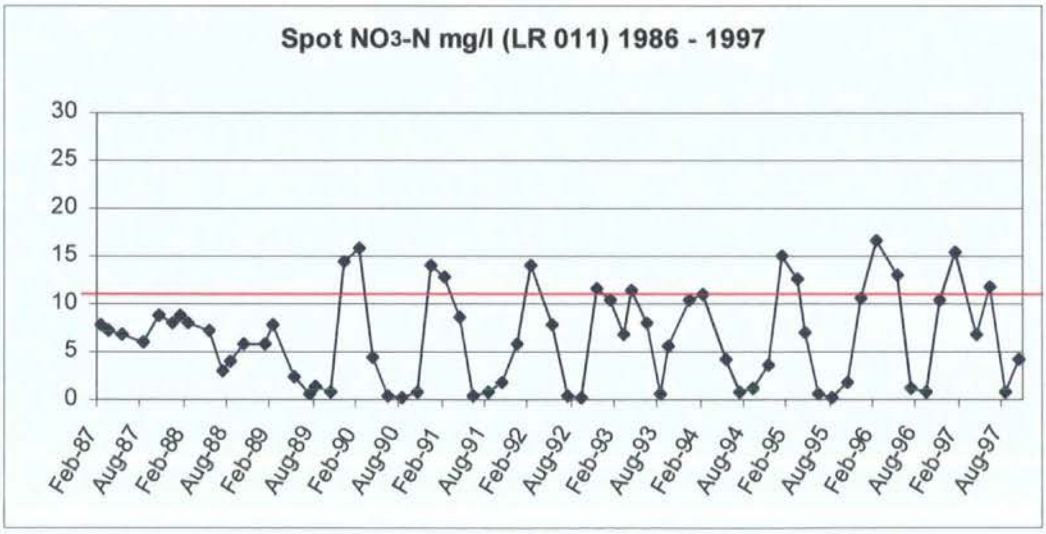


Figure 3.23 Site characteristics at LR011
Leet at Coldstream Gauge
OS Grid Ref: 383900 639600

Area: 4.77 km^2
Arable 29%
Pasture 4%

Reach length: 4000 m

Min / max width (m): 2.8 – 7.35
Min / max depth (m): 0.07 – 1.01
Min / max velocity (m^{3}s^{-1}): 0.016 – 5.75



3.3 Summary

The descriptions of the monitoring sites in this chapter have shown that this catchment has a history of poor water quality. This has been exacerbated by land management practices such as under-draining of fields, over use of fertilisers and allowing livestock access to the water courses. To bring the SEPA data up to date the results from water quality monitoring undertaken during the research period are presented and discussed in Chapter Six. The recent data will show that water quality is still an important issue in the catchment and that information that can help predict the outcome of land use change scenarios will be useful for stakeholders to include in their decision making processes. The methodologies required to meet the objectives of the research project are described below in Chapter Four and Chapter Five.

Chapter Four:

A methodology for evaluating the impact of land use and policy on water quality

4.1 Introduction

Water quality data show that the Leet Catchment has a history of poor water quality. To meet the objectives of evaluating the impact of land use and policy on water quality raises the key question in this thesis:

- Why, despite 20 years of water quality legislation is there still a nitrate problem in this catchment and many other parts of the UK?

To answer this, the methodology needs to address the following research questions:

- How do farmers' knowledge and day-to-day farming practices contribute to poor water quality in the Leet catchment?

- To what extent can policy designed to improve water quality be implemented in a small catchment?

- How does the knowledge transfer process affect successful implementation of policy decisions?

- Can an accurate high-resolution agricultural land cover map at field scale be derived from Remote Sensing imagery?

- To what extent can tried and tested models such as the export coefficient approach and the INCA water quality model predict the impacts of changing land use and management practices?

To address these issues requires a methodology that combines social and natural science techniques. These include the design and implementation of a postal survey and interviews with stakeholder groups; creating a land cover map from a variety of sources, such as aerial photographs and remote sensed digital data; and water quality monitoring and modelling. In this chapter the social science methodology is described.

4.2 Leet catchment farmers' survey methodology

The recent introduction of EU Water Framework Directive (WFD) (2000/60/EC) led the Scottish Executive to designate large areas of Scotland as Nitrate Vulnerable Zones (NVZs). The Leet Catchment is within the Lothian and Borders NVZ. As discussed in Chapter Two, documentation accompanying this legislation sets outs the rules for land management for farmers within an NVZ. One of the key requirements of this research was to understand stakeholders' perceptions of the impact of such legislation and what barriers there are to complying fully with the requirements of these and similar regulations. The methodology employed to achieve this initially focused on a structured postal questionnaire to farmers followed by in-depth, one-to-one confidential interviews with members of the farming community and other interested parties.

4.2.1 Objectives of farmers' structured questionnaire and interviews

The initial structured questionnaire design had to provide data that would enable the

- Compilation of a broad biographical picture of the farming community;
- Assessment of farmers' knowledge of EU policy and agricultural guidelines;
- Identification of perceived barriers to complying with regulations;

- Identification of other issues within the farming community;
- Willingness of farmers to take part in in-depth one-to-one interviews.

4.2.2 Developing the structured questionnaire

It was decided at an early stage that the structured survey should be as easy to complete as possible. Strategies included confining the questionnaire to two sides of A4 paper so that the length of the questionnaire would not put off respondents. Answers to questions would mostly require selection from a multiple-choice list. There would be a limited number of extended answers or personal opinions requested. This approach had the advantage that multiple choice answers were easy to complete but also the added benefit of pre-coding for later analysis using statistical analysis packages such as SPSS.

The questionnaire was set out in clear sections. Sections one and two concentrated on farm type and farmer biographical information, section three on knowledge of relevant EU policy and agricultural guidelines, and section four on issues relating to water quality. Finally, a question on willingness to take part in one-to-one and group interviews was included at the end.

4.2.3 Piloting the structured questionnaire

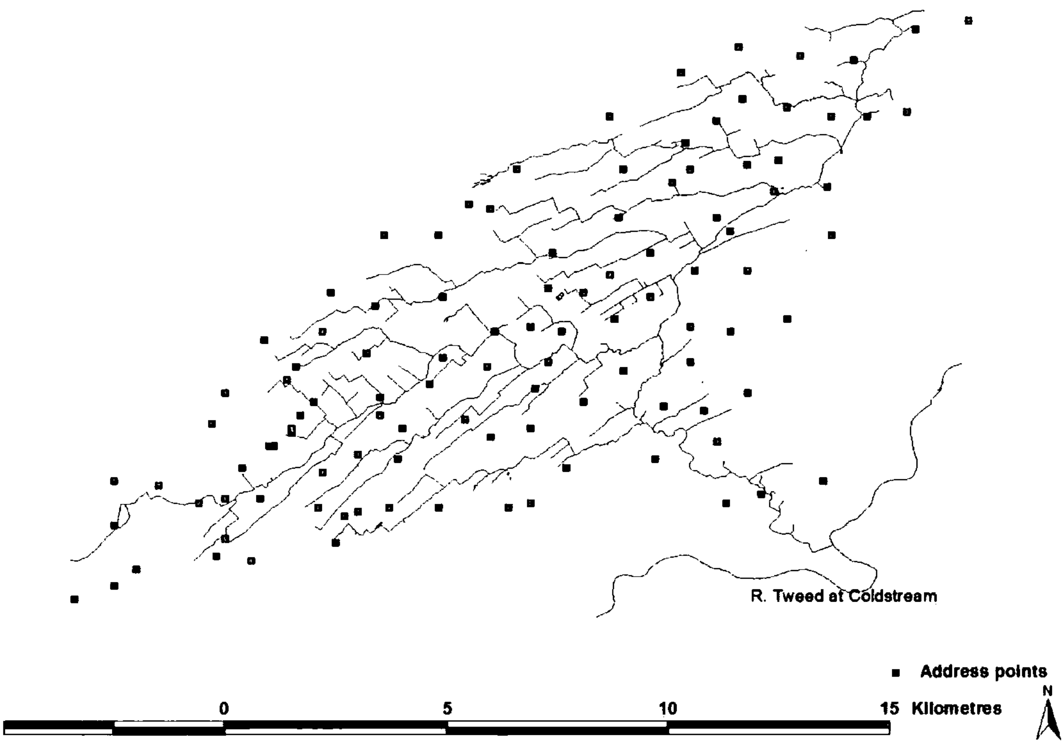
Piloting the questionnaire was considered to be particularly important. With limited experience of the farming community, it was essential to establish that the questions were relevant, unambiguous and written in language that was appropriate. The pilot survey was conducted with a small group (four) of articulate and well educated semi-retired farmers from North Yorkshire in an informal atmosphere, with the researcher present. This particular group was chosen as there was a personal contact with one of the farmers, and it was known that they would have a good knowledge of current and prospective water quality legislation. It was also thought that this particular group would complete the questionnaire accurately within their knowledge, and also be prepared to give honest and constructive comments on its contents and appearance. Discussion with the farmers and the use of a feedback sheet were used to gather comments for revising the questionnaire. After further discussions with doctoral supervisors a final questionnaire was produced and is included in Appendix 1a.

An introductory letter (Appendix 1b) was drafted to accompany the postal questionnaire. A stamped addressed envelope for reply was included in the questionnaire mailing, as this would be likely to increase the response rate.

4.2.4 Identifying potential survey respondents

SEPA supplied a partial list of farms, but it was known that this was not complete and, due to confidentiality issues, full postal addresses were not included. Therefore, the OS 1:25000 Explorer map (no. 339) was used to identify names of what appeared to be farms that could be included in the survey. This scale map was chosen as field boundaries and building names are clearly indicated. A list of 108 potential respondents was drawn up. At this stage the true number of working farms was unknown, and it was also unknown as to whether the associated land was outside the extent of the catchment. However, as this (108) is a relatively small number it was decided to survey all address points rather than try to select a smaller representative sample. This would serve two purposes: a full coverage of all farms would be achieved; and also farm amalgamations could probably be identified (for example, where a farm house has been sold off when land had been acquired by other landowners). Larger studies have indicated sampling strategies for selecting respondents, such as using random numbers, or selecting every *n*th entry. However, if this strategy had been adopted here, there was a risk that some farms might have been 'lost' from the survey. By selecting all 108 potential points, this minimised the risk of failing to discover all the farms. Figure 4.1 below shows the distribution of all address points across the catchment.

Figure 4.1 Location of 108 address points for questionnaire



The Thompson local directory for the Borders Region of Scotland, and the Royal Mail Post-Code finder were trawled to match 'farm names' to a postcode to complete the address list. The structured questionnaire was posted on 30th May 2002.

4.2.5 Response Rates

The initial response rate to the postal survey was promising. Within 21 days, 39 replies had been received. Some of these were from address points that were no longer working farms. These address points were removed from the data set.

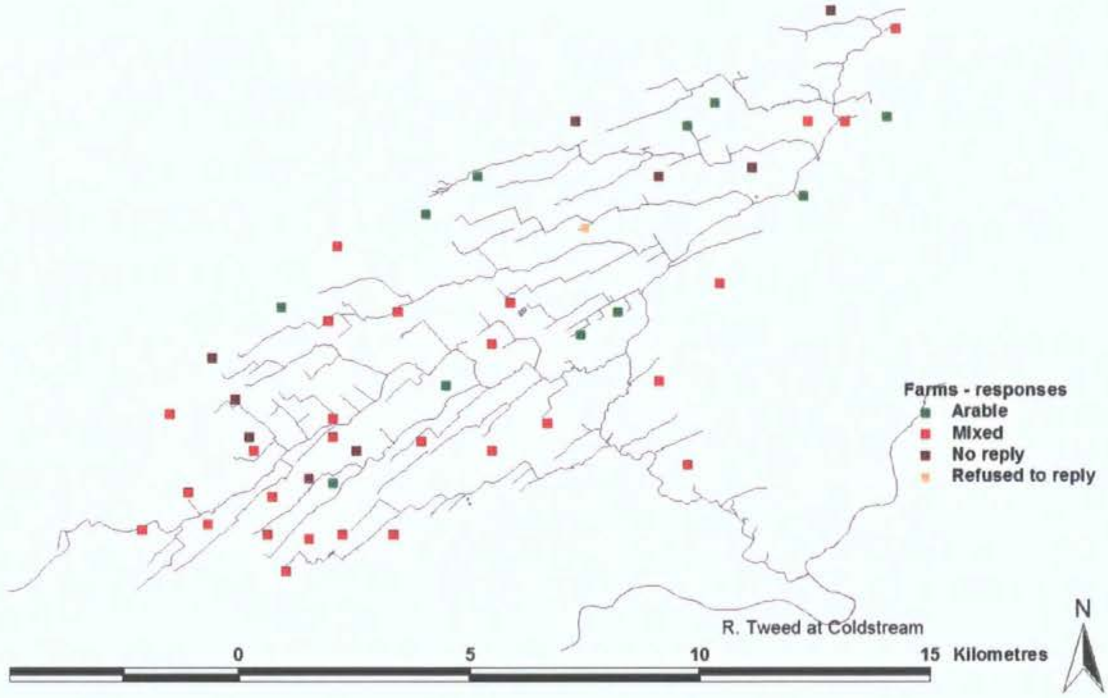
To improve the response rate a second postal survey (using the same questionnaire) was sent out on the 20th June again with a stamped addressed reply envelope. By 13th August the response rate had increased to 53 replies. It was decided to chase up the non-responses. Yellow Pages and the Thompson local directory were again trawled to obtain telephone numbers of the remaining 55 non-respondents. Phone numbers of 33 address points were obtained and phone calls politely requesting the return of the questionnaire were made. This only resulted in a further three responses as most of the phone calls were not answered. This was probably due to the restriction of the times at which phone calls could be made. However, a personal visit to the study area (August 24th, a bank holiday weekend) enabled the researcher to 'knock on doors' of non-respondents. This was a more successful strategy as it identified several address points as no longer being working farms, some farms that were outside the catchment, and two further address points that had recently been vacated due to farm amalgamations. By 1st October there were only 19 non-responses remaining. A list of these 19 addresses was sent to SEPA who confirmed which points could be eliminated from the survey by reason of being outside the catchment or no longer classed as a working farm.

The final response rate to the 108 points surveyed was: 45 points - no longer working farms; 15 points - wholly outside the catchment; 9 continued to produce no response; 1 outright refusal to return questionnaire; and 38 produced positive replies giving a total of 108. For the purpose of analysis the 15 farms outside the catchment and the 45 address points that were no longer working farms were removed from the data set, leaving 48 valid working farms within the catchment (figure 4.2.and table 4.1 below).

Table 4.1 Questionnaire responses

	Number	Percentage
Arable farms (type a)	11	22.9
Mixed farms (type c)	27	56.3
No response	9	18.8
Refused to reply	1	2.1
Total	48	100

Figure 4.2 Distribution of farm responses



Although chasing up non-responses had been time consuming, this strategy enabled the response rate to be increased considerably. Using the information about size, type and tenure of farm show these 38 (79.2%) positive responses to the survey provided the research with a database that can be taken as representative of the farming community in the catchment. For example, the responses cover an area of 10,342 Ha, approximately 90% of the total catchment and the range of livestock kept includes ewes and lambs; dairy and beef cattle; pigs and chickens.

4.2.6 Questionnaire summary results

The preliminary results of the questionnaire are described here as these formed the basis of developing the second stage of stakeholder contact.

The results of the 38 positive replies are tabulated in Appendix 1c. These comprise biographical details of the farm respondent and farm type such as:

- Tenure and farm size;
- Educational status, age group and gender of farmer;
- Membership of a quality assurance scheme;
- Farmers' consent to interview.

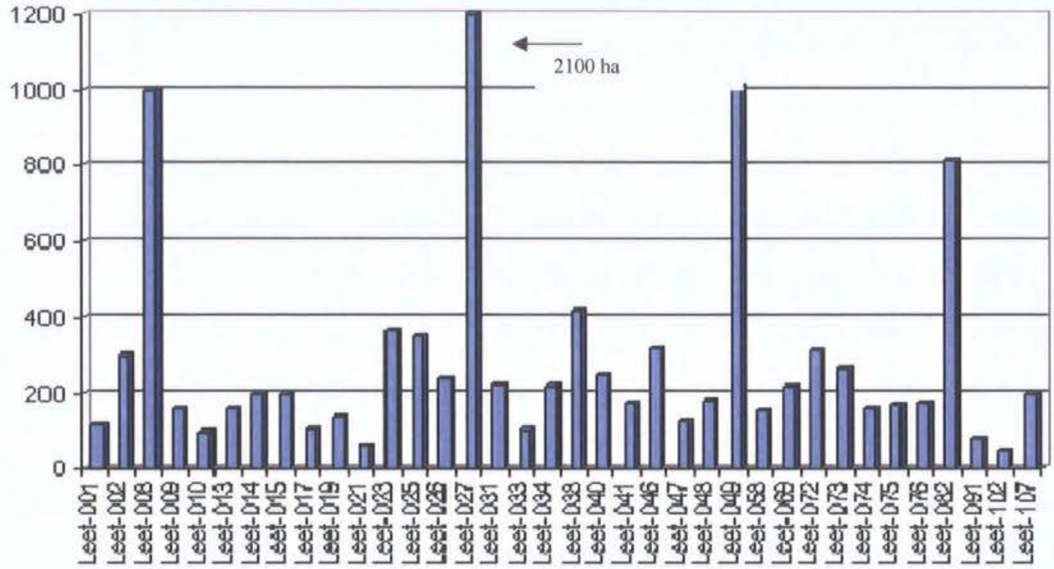
Further tables describe the results of questions on:

- Knowledge and understanding of agricultural regulations and guidelines;
- Availability and quality of advice;
- Perceived threats of agricultural pollution to water quality.

In summary the questionnaire data reveal that 29 (60.4%) of the farms are owner occupied, 6 (12.5%) are tenanted, and 2 (4.2%) are part of a larger business organisation. Educational status indicates that 4 (8.3%) farmers are school leavers, 20 (41.7%) completed college courses and 13 (27.1%) have a university degree. The ages group of the farmers are as follows: 7 (14.6%) are in the 25-39 group; 16 (33.3%) are 40-45; and 14 (29.2%) are 55 – 69 [17]. All the farmers who responded are male. There is one very large estate of 2100 ha that is part of a larger business enterprise and is the result of long-term acquisitions and farm amalgamations. Generally individual farm sizes range from 46 hectares to 1010 hectares. However, three of these are over 800 hectares and 34 of the farms are less than 400 hectares in size as Figure 4.3 below shows.

[17] Percentage figures do not add up to 100%, as some respondents did not give details to all questions.

Figure 4.3 Farm size (hectares)



The results from section three of the questionnaire (Knowledge and understanding of EU policy and agricultural guidelines) were coded in such a way as to give each respondent a total score on overall knowledge and understanding of the:

- Nitrates in Water Directive;
- Water Framework Directive;
- Bathing Water Directive;
- NVZ proposal for Scotland;
- PEPFAA code [18];
- PEPFAA (Nitrogen and Phosphorus Supplement);
- Farm Waste Management Plan;
- Fertiliser and Manure Plan;
- Rural (countryside) Stewardship Scheme.

For each of nine documents and regulations, respondents were given a choice of seven responses ranging from (a) to (g), shown in table 4.2. below. These responses were given a score ranging from 1 for 'have heard about it' to 5 for 'have read and understood it'. For full knowledge and understanding of all the documents a

[18] PEPFAA - Prevention of Environmental Pollution from Agricultural Activity

maximum of score of 45 could be achieved (0 was scored for responses 'a' and 'c', 'have not heard about it' and 'have received a copy but not read it').

Table 4.2 Knowledge of regulations score values

Response	Questionnaire letter code	Score value
have not heard about it	a	0
have heard about it, but not received a copy	b	1
have received a copy, but not read it	c	0
have read parts of it	d	2
have read it but would like to know more about it	e	3
have read all of it	f	4
have read and understand it	g	5

These score values were totalled enabling farmers' knowledge of regulations and guidelines to be described on a scale varying from very good (score above 36) to very poor (score below 9). Table 4.3 shows that 72% of the farmers have poor or very poor knowledge and understanding of these documents, with only 10% having good or very good knowledge and understanding.

Table 4.3 Farmers' knowledge of regulations - scores and percentage

	Total score	Number of farmers	Percentage in group
Very poor	0 – 9	8	22
Poor	10 – 18	19	50
Adequate	19 - 27	7	18
Good	28 – 35	2	5
Very good	36 - 45	2	5

At the time of survey, only one farmer had not heard about the Nitrate Vulnerable Zone proposal or Rural (countryside) Stewardship Scheme. On the other hand the Water Framework Directive and Bathing Water Directive were the least well-known pieces of EU legislation with only 26 and 23 farmers respectively out of 38 having heard of them. If these two latter documents are removed from the knowledge score, farmers' overall knowledge and understanding scores improve as now 52% of the farmers fall into the poor and very poor bracket and 19% are in the good or very good group (table 4.4. below). Although farmers seems to be quite knowledgeable about the NVZ proposal, their knowledge of the PEPFAA code and its N and P supplement are quite poor with 47% and 70% of farmers having not heard about or not read them. This is quite alarming as these two documents set out in a clear and concise manner what is and is not allowed under the NVZ designation.

Table 4.4 Farmers' knowledge of selected regulations - scores and percentage

	Total score	Number of farmers	Percentage in group
Very poor	0-7	7	18
Poor	8-14	13	34
Adequate	15-21	11	29
Good	22-28	4	11
Very good	29-35	3	8

Section three of the questionnaire asked if farmers had sought advice on any of the documents listed. Nine of the farmers did not answer this question and 25% of those who responded, had not sought any advice. Of the remaining 16 farmers, 22% thought advice received was good or very good, but 23% thought advice was only adequate or poor.

In section four, farmers were asked to what extent they thought water quality is threatened by agricultural activity. The results show that 2 (5%) farmers do not think that agriculture affects water quality at all, 17 (45%) consider agriculture has a slight effect, 11 (29%) think water quality is moderately affected by agriculture and only 7 (18%) of the farmers thought there was a significant threat to water quality.

The open-ended questions in section four enabled farmers to write their own answers on what they perceived to be the most important barriers to complying with water quality regulations. An SPSS code book was prepared to code up the responses to sections 4.5 and 4.6. All questionnaires were scanned for common themes that could be used as the variable. Twenty-two themes were identified, but it was very difficult to give a meaningful name to each variable within the 8 character requirements of SPSS, a simple alphabet listing was used instead (table 4.5 below). Coding instruction could then be given a Yes/No response to each statement.

Most of the farmers made more than one comment in these sections enabling graphs to be produced from their multiple responses. Figure 4.4 below illustrates the perceived barriers to compliance with EU legislation and agricultural guidelines.

Table 4.5 Comments, codes, responses: perceived barriers to regulation compliance

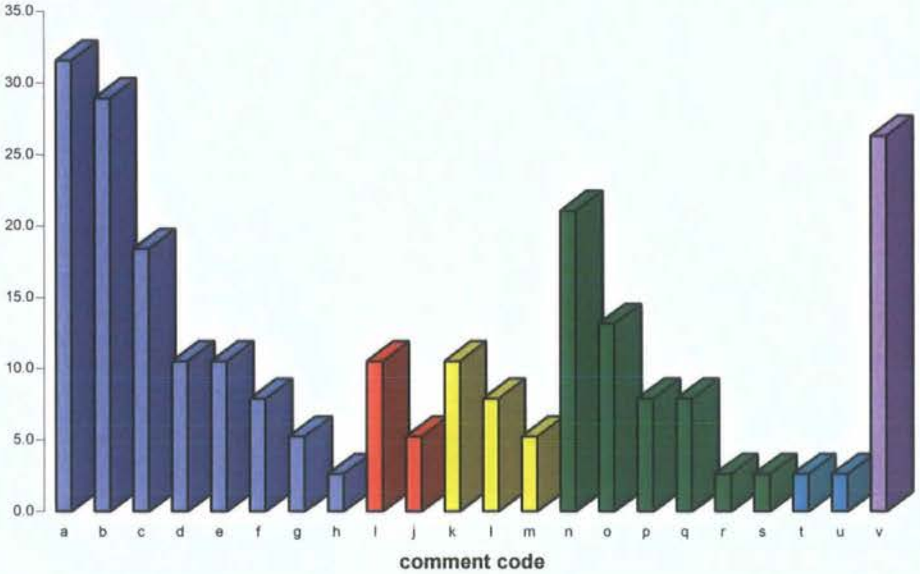
Comment Code	Code	Number of agreements	%
Too much paper work / too bureaucratic	a	12	31.6
Too much legislation / too many schemes	b	11	28.9
Not enough time for reading / completing paperwork	c	7	18.4
Legislation / regulations need to be more concise	d	4	10.5
Regulations need to be justified at the local level	e	4	10.5
Too many changes in legislation / regulations	f	3	7.9
Legislation too difficult to comply with	g	2	5.3
Sufficient regulations in place	h	1	2.6
Need proof agriculture is responsible for pollution	i	4	10.5
Other groups to blame for pollution	j	2	5.3
Other EU states do not comply with regulations	k	4	10.5
See EU (or others) as ill-informed or not experts	l	3	7.9
Regulators do not listen to landowners	m	2	5.3
Poor state of agriculture / farming not profitable	n	8	21.1
Lack of funds	o	5	13.2
Compensation required	p	3	7.9
Cost of tests	q	3	7.9
Full costs of implementation needs to be known	r	1	2.6
Need a way of passing on costs to consumer	s	1	2.6
Counter-productive to limit timing of fertiliser	t	1	2.6
Preference for 'Old' farming methods	u	1	2.6
No comments at all	v	10	26.3

The results of the survey found that the five most frequent answers farmers gave for being unable to fully comply with EU regulations and guidelines were:

- There is too much paper work and schemes are too bureaucratic;
- There is too much legislation or too many schemes;
- Poor state of agriculture / farming not profitable;
- There is not enough time for reading / doing paperwork;

- There is a lack of funds to implement new ideas.

Figure 4.4 Perceived barriers (percentage response) to compliance with EU legislation and agricultural guidelines



The findings from the postal questionnaire described above, were invaluable to the research as they identified the issues that the farmers considered to be important and formed the basis of the question topics for the one-to-one in-depth interviews.

4.2.7 Analysis of preliminary results

In an attempt to understand why there was a gap in the knowledge and understanding of documentation as identified in table 4.3, a simple description of results was applied to the data from the questionnaire. Qualitative analysis was carried out on the data, for example, examining the relationship between the education, age and ownership status of the farmers and their knowledge and understanding of the nine documents, and, their perceptions of the barriers to complying with regulations. The data was tabulated then used to plot scatter graphs (figures 4.5 a-e and table 4.6 below). However, the graphs are limited as they show no linear correlation could be found between level of knowledge and the variables of a) age group; b) level of education; c) farm ownership and d) farm type.

Table 4.6 Number of farmers within each variable group

	(group 1)	(group 2)	(group 3)	(group 4)	(group 5)
Knowledge	Very poor 8	Poor 19	Adequate 7	Good 2	Very good 2
Age	16 – 24 0	25-39 7	40-54 16	55-69 14	70+ 0
Education	School leaver 4	College 20	University 13		
Farm type	Arable 14	Livestock 0	Mixed 23		
Farm ownership	Owner 29	Tenant 6	Large Business 2	Other 0	

Statistical analysis using Chi-square was then applied to the data to test the relationships between variables, using the null hypothesis "Knowledge and understanding of water quality regulations and guidelines is not related to i) age group; ii) level of education; iii) farm tenure". The calculation of the Chi-square equation is included in Appendix 1e. Chi-square values of 8.49 for age group, 5.19 for education level and 2.77 for farm tenure were returned. With 16, 8 and 8 degrees of freedom for each group, the 0.05 probability values of 26.3, 15.51 and 15.51 indicate that the null hypothesis has to be accepted. Therefore there is no statistically confident correlation between knowledge and understanding of regulations and the variables tested. This result means that there is not a simple answer to why there is a knowledge gap relating to the regulations and guidelines and this is an issue that needs to be explored further during the in-depth interviews with the stakeholders.

[19]

Figure 4.5a Knowledge and age group

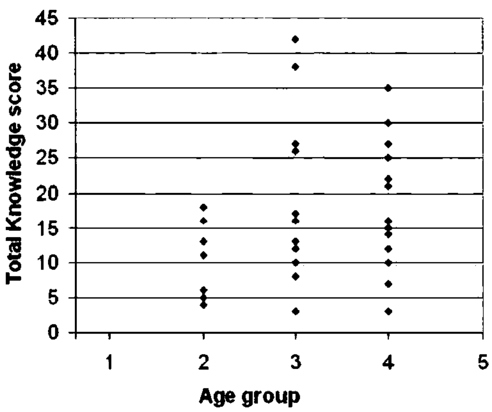


Figure 4.5b Knowledge and education

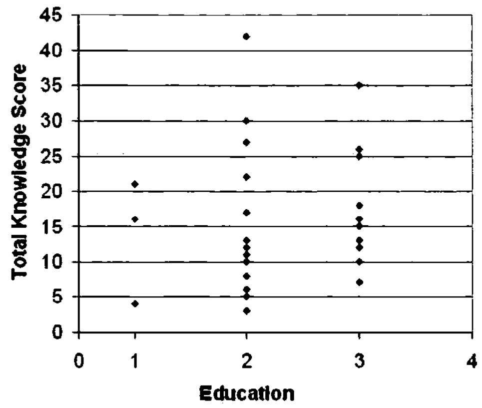


Figure 4.5c Knowledge and ownership

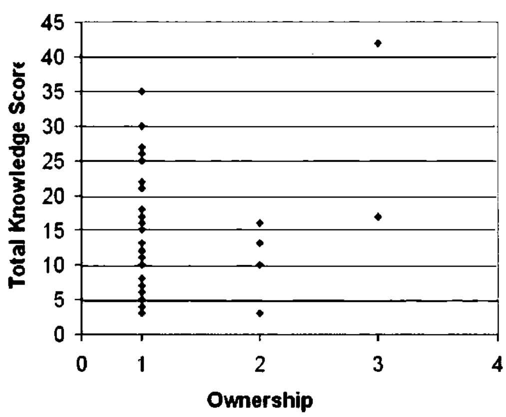


Figure 4.5d Knowledge and farm type

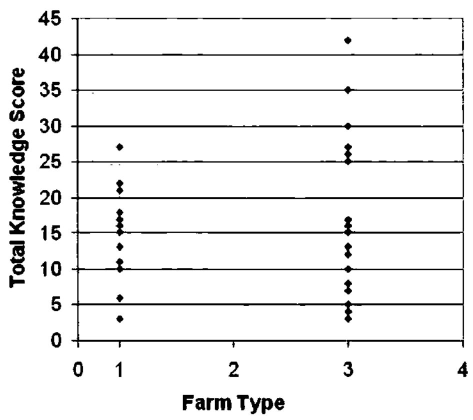
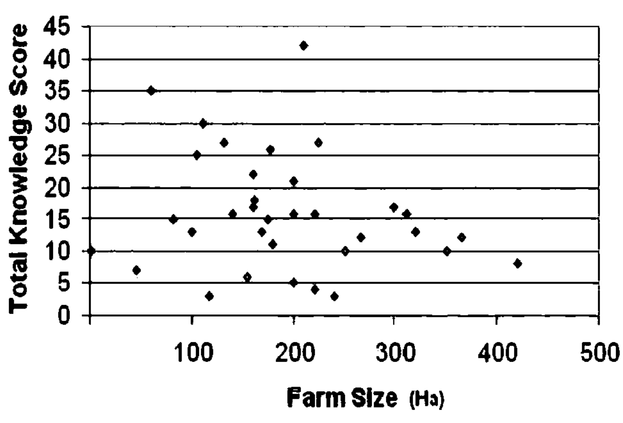


Figure 4.5e Knowledge and farm size



[19] Category of groups 1-5 in graphs a,b,c,d, shown in table 4.6

However, the graphs enable generalisations to be drawn on the extent of knowledge and understanding and therefore the type of farmer that may be more likely to fall into the knowledge gap can be identified. The two key generalisations are that:

- Poorest knowledge and understanding (scoring 0-14 points) would be found where the farmer has a school leaver level of education, is in the younger age group (aged 25-39) and has a small, tenant farm.

- Good to very good knowledge and understanding would be found where a farmer had a college or university education, was over 40 and an owner occupier or farming as part of a larger business concern.

This analysis has identified some of the characteristics that contribute to a knowledge gap and these are issues that need to be addressed when government formulates documents relating to mandatory requirements and guideline.

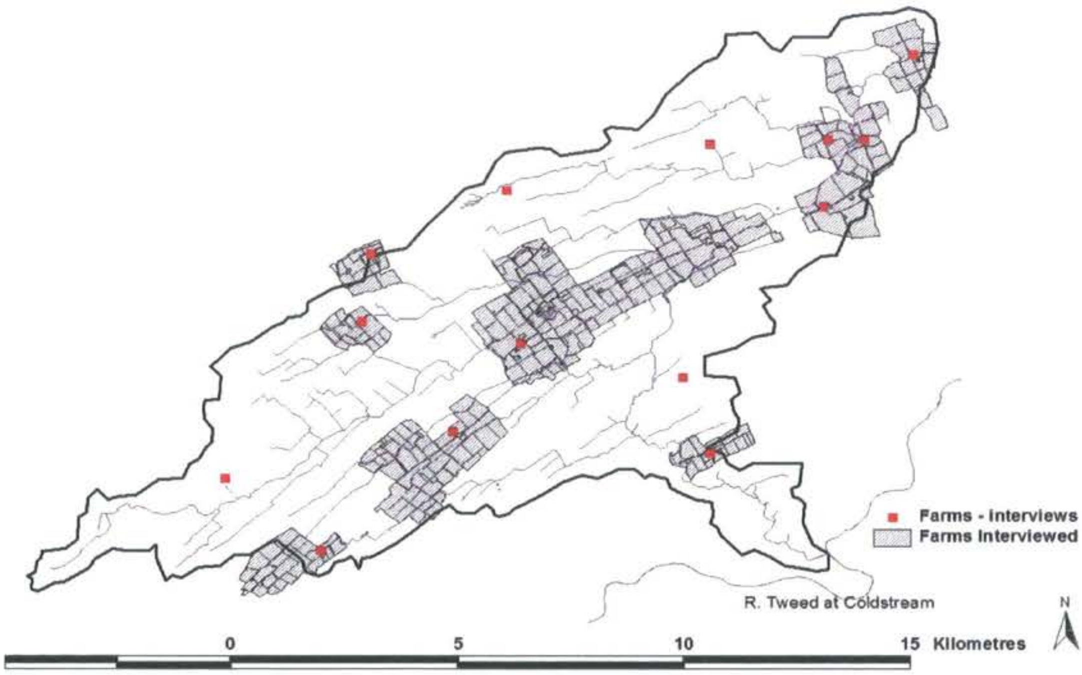
4.2.8 Conclusions from the postal survey

A significant statistical relationship between the extent of farmers' knowledge of regulations and biographical details cannot be established due to insufficient variance in the independent variables, for example, only three values 1, 2, or 3, were available for education group and farm type and five values for the age groups. If more values, say, of the age or precise educational achievements of individual farmers were available then further statistical analysis may have been possible. However, the main aim of the postal questionnaire was not to produce high quality data for statistical analysis, but to provide key points on which to base the one-to-one, in depth interviews. In this respect the questionnaire was very successful.

The high positive response rate (79.2%) to the postal survey, means that it is reasonable to say that the responses are representative of the targeted farming community, particularly in terms of size, distribution and tenure of farming unit. However, it is known that certain types of 'farm' are not represented. There are at least two specialist poultry units and one pig unit within the catchment. Unfortunately there was no response from these farms. A further attempt to make contact with these farms was made in February 2003 to try to include their responses, but without success. Farmers' comments on issues relating to water quality regulations have been frank and therefore very helpful in the preparation of key points for the interviews.

From the postal survey, 14 farmers stated they would participate in the in-depth interview stage of this research. The distribution of these farms is shown on figure 4.6, indicating there is a good representation of interviewees in terms of size, farm type and location of farms within the catchment.

Figure 4.6 Distribution of farm interviewed



4.3 In-depth one-to-one stakeholder interviews

4.3.1 Rationale of interviews

The main aim of the in-depth interviews was to obtain primary data to enable the examination of situational, psychological, sociological, economic, and behavioural factors that influence farmer's decision making as to whether to adopt or not adopt management strategies and/or guidelines set out in existing and proposed water quality regulations and legislation. The interviews were conducted in a hierarchical order. Firstly interviews focused on the farming community, then local advisory and non-governmental organisations, then statutory bodies, and finally the Scottish Executive. All interviews were taped with interviewees' consent, then transcribed for analysis.

4.3.2 Interview structure

The interviews were semi-structured, with questions set out in themes, and the interviewer was familiar with these before undertaking an interview. This approach had the advantage that if discussion on one theme overlapped with another, or if the interviewee changed the focus of the original question, the interviewer was able to continue that thread to its conclusion, then bring the interviewee back to the next theme.

In devising the questions, care was taken to ensure questions were worded in such a way as to allow stakeholders to express their views in their own terms of reference and not be led by the interviewer. However, the interviewer needed to draw on answers from the structured questionnaire (although completed questionnaires were not taken to interview), for example, when asking about NVZ and other specific guideline documents, questions were preceded by phrases such as "the postal survey indicated that..." or, "to what extent do you think ...."

To be successful, the interviews needed to produce responses that were honest and frank answers to what could be sensitive issues. To achieve this, the interview began with questions that were non-threatening or sensitive, aiming to put the interviewee at ease so that he/she would be more willing to answer more sensitive questions later on. In effect there were a few moments in which to gain the trust of the interviewee and demonstrate that the interviewer was not part of the regulatory authority but conducting independent research. When interviewing members of the farming community, it was also important that the interviewer demonstrated empathy with farmers and their perceptions of regulations and guidelines whilst maintaining a 'neutral' stance in posing questions. For example, farmers' interviews started with situational characteristics questions such as confirming farm size, location, tenure, farm type, crop type / livestock type, and intensity. Drawing on known biographical detail of the farm from the structured questionnaire as part of the introduction to the interview helped to relax the interviewee. This approach also had the advantage of allowing the farmer to feel that the interviewer has taken an interest in his/her personal situation rather than being indifferent to them as individuals.

The question topics for the farmers' interviews were based on the responses from the structured questionnaire. Question topics for the other interested parties also included themes that were revealed during the farmers' interviews. The farmers' interview was piloted with a farm holding in the Scottish Borders, close to the study site and partially within the NVZ. The farmer concerned had been the chair of the local FWAG[20], so was fully aware of the implications of the NVZ proposal. In addition the family had already made significant agri-environmental changes to farming practices under a successful award from the Rural Stewardship Scheme. This expert knowledge enabled final refinements to the interview structure to be made. Interview topics are included in Appendix 2.

4.3.3 Preliminary interview results

Setting up the farmers' interviews was problematical. A preferred month for interview had been indicated on the questionnaire, most by the end of the harvest period (post October 2002). However, it proved very difficult to make contact by phone during office hours. Contact was then made by letter, with a reply slip suggesting potential dates and times and a stamped addressed envelope resulting in a greater response.

Ten in-depth interviews with farmers were carried out between November 2002 and April 2003. All interviews were taped, and sent for transcription by an independent person; this helped to maintain the integrity of the interviews. Transcriptions were then checked to correct errors resulting from dialect, use of technical language and

[20] FWAG – Farming and Wildlife Advisory Group – an advisory organisation funded by members subscriptions "to provide farmers, crofters, landowners and our other clients with the best opportunity for environmental gain through cost effective, quality solutions". (http://www.fwag.org.uk/scotland/)

terminology. The interviews involved a good cross-section of the farming community in the Leet Catchment. Land holdings ranged from 100ha to 2000ha, and represented almost 30 % of land cover in the catchment. All three farming types (arable, livestock, and mixed) were represented including a dairy unit. Land ownership included tenants, a managed estate and family-run farms, the length of family farm ownership ranging from one year to over 130 years. One of the farms had been affected by the foot and mouth outbreak of 2001, but had since been re-stocked. This mix of respondents and, in particular, a comparison of the views of small family-run farms with that of a very large business, provided an excellent insight into how farmers view the issue of water quality and pending WFD and NVZ requirements.

From the interviews, it was found that farmers do not deliberately disregard official documents in a wholesale manner, but that they do have criticisms of them. Documentation is received with scepticism, often perceiving that it will not be written in plain English, but will be full of jargon, or couched in terms that can be interpreted in different ways. They were particularly critical of the NVZ documentation, saying it was not clear who was 'in' or 'out', or what types of fertiliser were acceptable. Farmers think that many of the regulations are unnecessary and that most of the guidelines are common sense. They criticise the number of different forms to be completed, many of which overlap, for example information required on the IACS (Integrated Administration and Control System) forms for claiming subsidy overlap with grain and livestock Quality Assurance Schemes, manure management plans and many others. Furthermore, most of the farmers felt that the timing in sending out literature is poorly thought out.

The majority of farms in the catchment are run by one or two men. They say that finding the time to read and understand documents is crucial, especially if they want to apply for agri-environment schemes such as RSS[21]. The farmers were asked how the Government could encourage full compliance of regulations. All the farmers had strong feelings on this subject, saying similar things, such as the rules should be

[21] RSS – The Rural Stewardship Scheme is a Government funded, voluntary but competitive, agri-environment scheme to encourage adoption of farming practices for the protection and enhancement of the environment and sustainable rural development.

clearly set out and not open to different interpretations. To paraphrase several comments: "*the EU is trying to make the same legislation fit every country, so it is impossible to comply with all of it*". Most of the farmers also felt that other EU countries "*bend the rules to meet their own needs*" and this is unfair practice. They have a low opinion of the politicians saying that "*they've got bigger things to bother about than agriculture*". Farmers would rather see voluntary regulations, with benefits for those who fully comply. However, some of the farmers believe that licensed farming will be introduced within the next decade.

The majority of the farmers genuinely believe they are not responsible for high rates of nitrate pollution in the Leet and Lambden, stating "*it makes no economic sense to apply more fertiliser than necessary; [we] often apply less than the recommended quantity, purely on economic ground*". The arable farmers do not think the NVZ will affect them so much. They think the pig units and dairy herds will have greater problems complying with the regulations.

4.3.4 Interviews with advisors and regulators

Interviews with the leading advisors and regulators were carried out between October and December 2003. These included FWAG, SNH[22], SLF[23], Tweed Forum[24], NFU-S[25], SEPA and SEERAD[26]. In addition the SAC[27] was approached for interview, but declined on grounds of insufficient time and could not be included in the costing of their time management. The aim of these interviews was to gauge the 'official' response to the WFD and the NVZ designation. It was also an opportunity to put

22 SNH – Scottish Natural Heritage, advises government on the development of policy and the formulation of legislation relating to the natural heritage, including increasing awareness of countryside and conservation matters and carry out consultations on behalf of government. http://www.snh.org.uk/

23 SLF – Scottish Landowners Federation: represents interests of those involved with rural property and land management (http://www.slf.org.uk)

24 Tweed Forum – non-profit organisation established to ensure the sustainable management of the river Tweed and its catchment (http://www.tweedforum.com)

25 NFU-S – National Farmers' Union Scotland: the agricultural organisation representing 10,000 farmers, to promote and protect the interests of Scottish agriculture. http://www.nfus.org.uk

26 SEERAD – Scottish Executive Rural Affairs Department: the devolved Government department http://www.scotland.gov.uk/topics/agriculture

27 SAC – Scottish Agricultural College: supports agriculture through its specialist research and development resources, its education and training provision and its expert advisory and consultancy services. http://www.sac.ac.uk/

some of the fears expressed by the farming community to policy makers and regulators. Question topics are included in Appendix 2.

All the advisory agencies agreed that the aims of WFD are sound and there is a need for the designation of the NVZs. They all believed that farmers within designated areas would do their best to comply with regulations. However, all acknowledge that lack of time to read and understand the requirements may lead to some farmers unwittingly breaking the rules. All the advisory agencies thought record keeping needs to be streamlined and that SEERAD should be more proactive in this matter. The biggest criticism of the requirements of the NVZ is that the financial incentives could have been more generous and they fear that future monies realised through modulation[28] may go into general rural development schemes rather than back to the farming community for agri-environment schemes. When asked about the future of the advisory agencies themselves, all stated that they themselves were facing resource problems, emphasising that all 'jobs' must be fully costed and they also must chase funding for specific projects. This often prevents informal visits to the farming community and prohibits building up relationships with individual farmers.

4.4 <u>Summary</u>

The results from the postal questionnaire and interviews have highlighted several issues that are of great importance to the successful implementation of the requirements for WFD and the NVZ action plan. A key problem is that of a poor knowledge transfer process. The farmers stated that documents are often very lengthy and are often delivered at inappropriate times, e.g. during spring when farmers (both livestock and arable) are particularly busy and cannot find time to read them. This has led to the gaps in farmers' knowledge and understanding of relevant documentation and the perceived barriers to farmers' complying with the requirements of water quality legislation and guidelines. If knowledge transfer is to be improved then access to guidelines and relevant literature that is not couched in jargon, but written in language appropriate for the farming community and in a form that can be easily read, must be made available.

[28] Modulation – a variable percentage of a farmer's CAP subsidy 'clawed' back by Government.

The advisory agencies were also critical of the knowledge-transfer process, agreeing with many comments made by the farming community. Furthermore, the advisors will need to take on a more proactive role as changes in regulations become more apparent. To do this, the advisors will need to be seen to be experts capable of delivering sound, reliable and relevant advice.

The knowledge gap has been acknowledged by SEERAD, but its implications have not yet been fully addressed. As the requirements of WFD and the NVZs begin to take effect, this is an important issue that the policy makers and regulators will need to address urgently.

Chapter Five:

A natural science methodology for evaluating the impact of land use and policy on water quality

5.1 Addressing natural science methodologies

5.1.1 Introduction

The postal survey and stakeholders' interviews have showed there is a gap in farmers' knowledge and understanding of the water quality issue in the Leet catchment. To address this, there must be a mechanism to bridge this gap. Traditionally, models such as those discussed in Chapter Two have been used to demonstrate the impacts of pollutants on water quality. However, there are drawbacks to the use of such models:

- They rely on 'expert' analysis and the use of technical terminology;
- Non-scientists (e.g. the farming community) are often suspicious of, or do not understand the results;
- There can be a lack of trust in the scientific methods used (such as data gathering and interpretation);
- Often there has been little or no input from end users (such as the farming community);
- End users feel the results are not applicable to their situation.

In an attempt to address these issues, i.e. calibrate a model that predicts the impacts of land use change scenarios at the field scale and is appropriate for end users, the following questions must be addressed:

- Can multispectral remote sensed imagery and aerial photography define an accurate high-resolution agricultural land use map that distinguishes winter/spring sown arable crops as well as other fertilised/non-fertilised short vegetation at the field scale?

- Can the export coefficient approach or the INCA water quality model successfully predict the impacts of land use change scenarios at the field-scale in a small catchment?

- To what extent can the options described in Government agri-environment schemes provide real opportunities to comply with water quality improvements required under current legislation?

Seeking to answer these questions involved the following elements:

- Building a GIS database to be used as a visualisation tool for illustrating land use change scenarios and water quality data, comprising coverage of the drainage, field boundaries and other features within the catchment as required;

- Water quality monitoring and analysis carried out between October 2002 and September 2004 to bring the SEPA data set up to date;

- Interpretation of RS data acquired for the summer of 2002 to define a land cover map;

- Ground survey of land cover at the field scale for 2003 and 2004 providing data for the land use change scenario modelling in the INCA model.

The following sections of this chapter describe the methodology for each of these stages in the research. Where results help to clarify the procedure, these are also included. The main presentation of results comes later in chapters six and seven.

5.2 Building a GIS geo-database

5.2.1 Why use a geographical information system (GIS)?

A GIS is:

> *"A data input subsystem which collects and/or processes spatial data derived from existing maps, remote sensors and other data sources. It is a data storage and retrieval system which organises the spatial data in a form which permits it to be quickly retrieved by the user for subsequent analysis, as well as permitting rapid and accurate updates and corrections to be made to the spatial database"* (Chrisman, 1997).

In a GIS, digital images and map layers[29] that relate to real world features can be overlaid to create a combination of layers to be queried, analysed and manipulated to explore geographical data. This helps understand the relationships and links between inputs and outputs in a system and in turn aids management decisions. These capabilities make GIS a suitable visualisation tool for mapping, updating information and providing a decision support tool that can be used by a range of stakeholders.

5.2.2 Ordnance Survey digitised data

The first task in building suitable coverages for use in a GIS was to acquire digital data of the real-world features found on the ground. These include drainage data, field boundaries, and the location of buildings, roads and so forth. The Digimap service[30] makes Ordnance Survey data at a variety of scales and formats available to

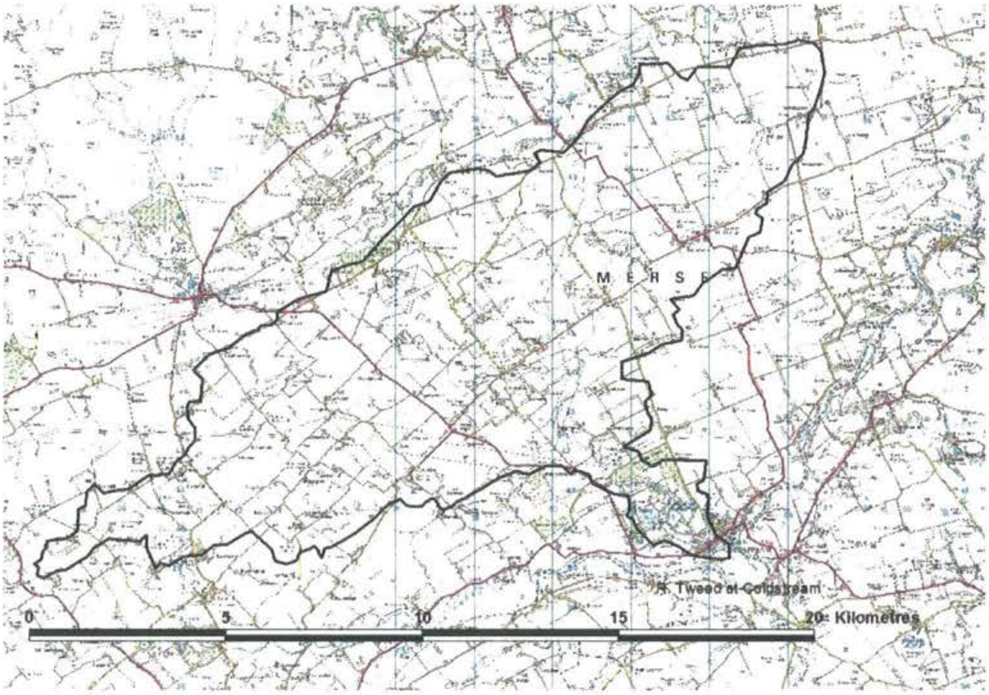
[29] Layers comprise line (also known as arcs or vertices), point or polygon data, to which attributes can be attached. They are usually referred to as 'coverages' or 'shapefiles'. Line data can be roads, rivers etc. Polygons represent bounded areas such as a building plot, parcel of land, county etc. Points can represent data found at a unique geographical co-ordinate such as by OS National Grid co-ordinates.

[30] http://www.edina.ac.uk/digimap

the academic community. Two common formats for creating land cover maps are MasterMap and Land-Line. MasterMap data are of superior quality – vector data sets are prepared as lines, points and polygons of features that match the coverages required. However, at the start of this research, MasterMap data were not freely available so Land-Line data, had by default to be requested. Land-Line digital map data are digitised from Ordnance Survey large scale maps and surveys comprising accurately surveyed positions of the natural and man-made features of the topography. The accuracy of Land-Line data varies, depending on whether an area is classified as urban, rural or mountain. The summary accuracy figure for urban (1:1,250 scale) is 0.4m, and for rural (1:2,500 scale) is 0.9 to 1.2m.

Data were requested using OS National Grid co-ordinates, in this case sufficient tiles within the rectangle of NT366638 – NT387653 that would include the extent of the catchment (figure 5.1 below).

Figure 5.1 OS extent of grid co-ordinates for the Leet catchment



The downloaded tiles (108 of them) comprise pre-coded line data matching features on the ground such as roads, building outlines, water features and so on, and are in a digital exchange format (dxf). This format requires conversion to shapefile format using MapManager software for use in ArcGIS products.

This conversion process also appends each tile (joins adjacent tiles) so that one large shapefile is achieved rather than many individual tiles, thus simplifying the editing tasks. After conversion the digitised data were viewed in the GIS. Figure 5.2 below, indicates all the features included in the initial shapefile as a single image. To make a meaningful map, layers relating to individual features were extracted. Specific feature codes were selected to make the shapefiles (layers) for mapping, for example:

Feature code	***Relates to feature name***
0001	Building outline
0021	Edge of road metalling
0030	General line (used for field boundaries)
0059	Water detail (used for the drainage)

Two map layers were made for the field boundaries (0030) and the drainage (0059) within the catchment, and are illustrated in figures 5.3 and 5.4 below.

Figure 5.2 Default digitised OS line data – all feature codes

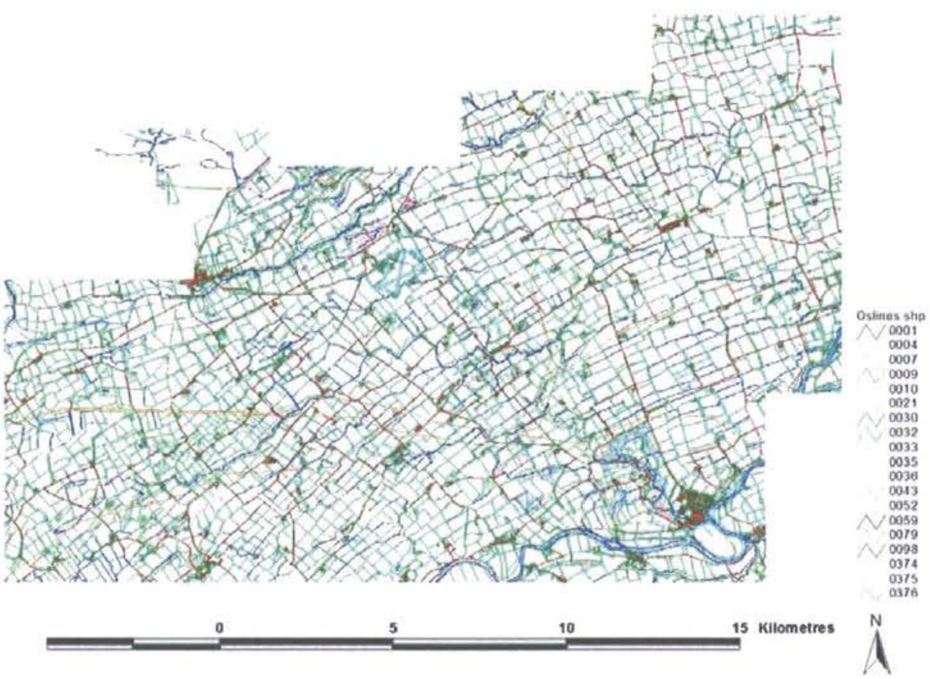


Figure 5.3 Coverage extracted to make field boundaries (feature code 0030)

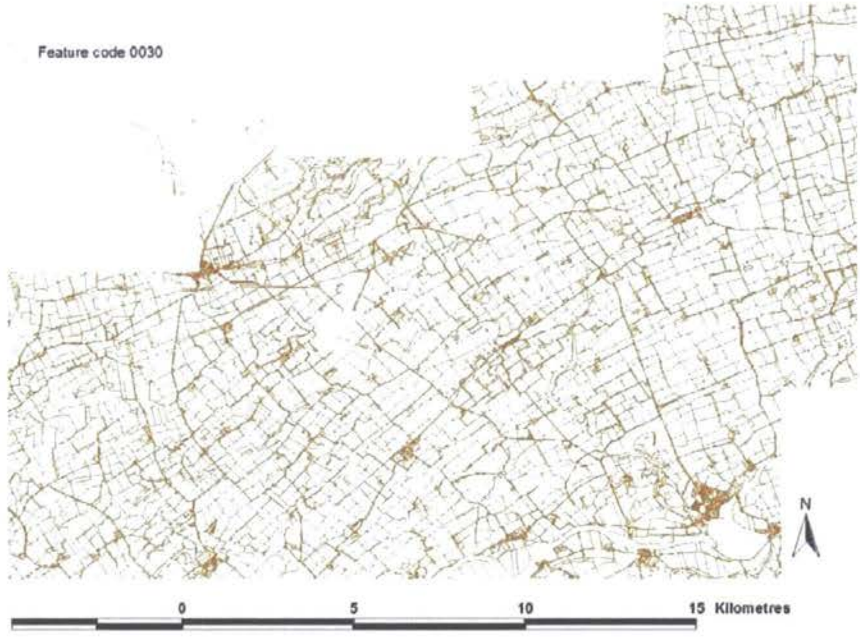
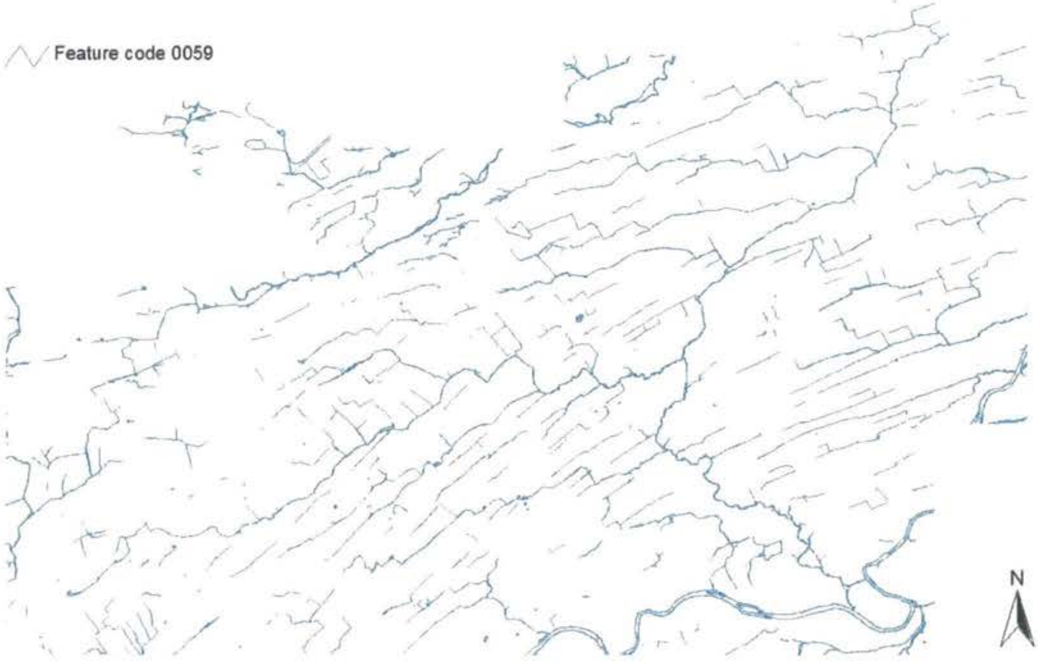


Figure 5.4 Coverage extracted to make water courses (from feature code 0059)

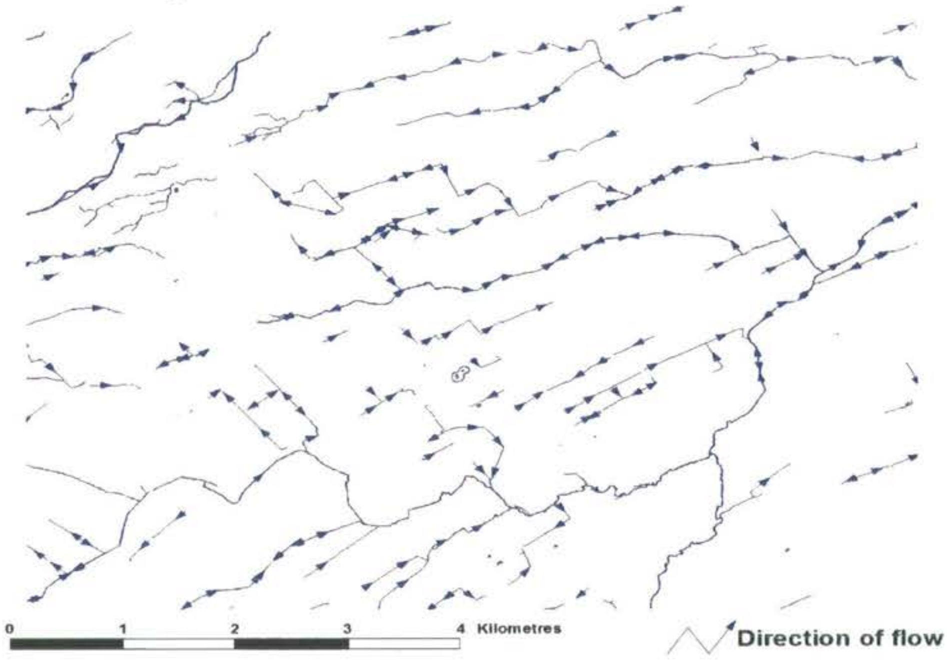


However on close inspection these layers (figures 5.3. and 5.4) were found to have serious errors. When polygons were made from the lines using feature code 0030 to find the extent of fields, many of the lines would not form polygons (figure 5.5

below). A similar problem was found with the line data when making a drainage network. There were a very large number of gaps between segments of watercourse which prevented a linear routing network from being made (figure 5.6 below).

Figure 5.5 Polygon errors from feature code 0030

Figure 5.6 Routing errors from feature code 0059



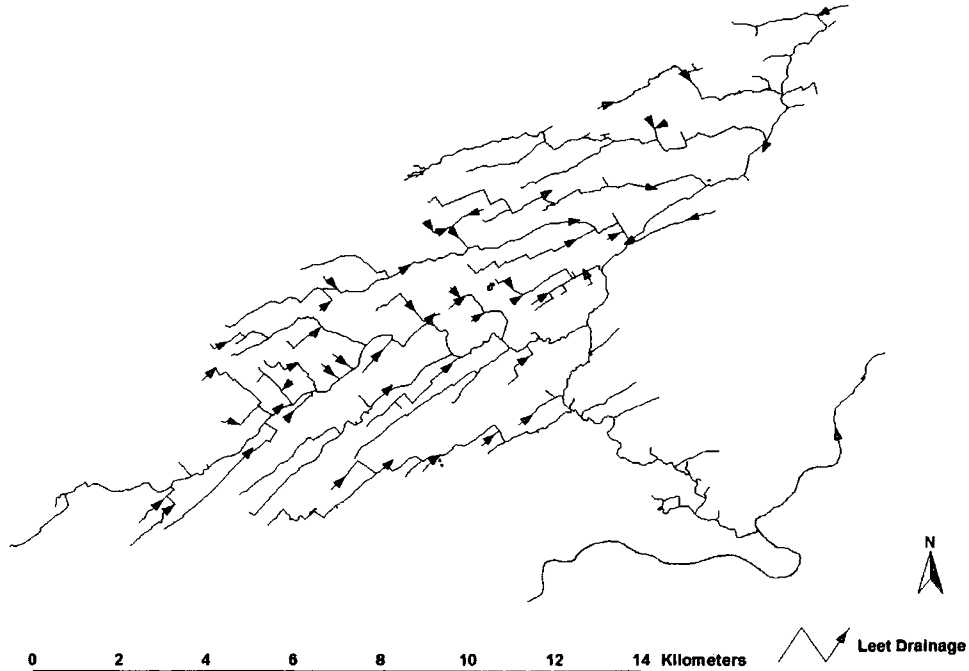
In figure 5.5 two types of errors were identified. There are areas where the polygon was not closed, so not identified as an existing plot of land. These are displayed as white areas on the image. There were also completed polygons that have missing boundaries, e.g. four fields are shown as one very large area. Figure 5.6 illustrates the errors in the drainage coverage by using an arrow symbol. The arrows indicate the direction in which each segment was digitised – this should correlate to the direction of flow for each stream segment. In an accurate drainage layer, all arrows should be facing downstream. Here they can be seen to be facing both upstream and downstream. In addition, there are significant gaps between segments. This is where the OS line data have not recorded a line relating to part of the water features. These errors were caused during the automated digitising process. Existing OS paper maps were digitally scanned, and line features coded. Errors therefore occurred where lines of one feature intersect or are overlaid with another. For example, the image (figure 5.7) below illustrates a section on the OS 1:50000 map where, in reality, the watercourses flow beneath roads, bridges and so forth, but these are shown as broken segments on the map. Errors such as this need to be corrected before the layer can be used in a water quality model.

Figure 5.7 Example of errors that carry over to automated digitising

5.2.3 *Correcting line and polygon errors*

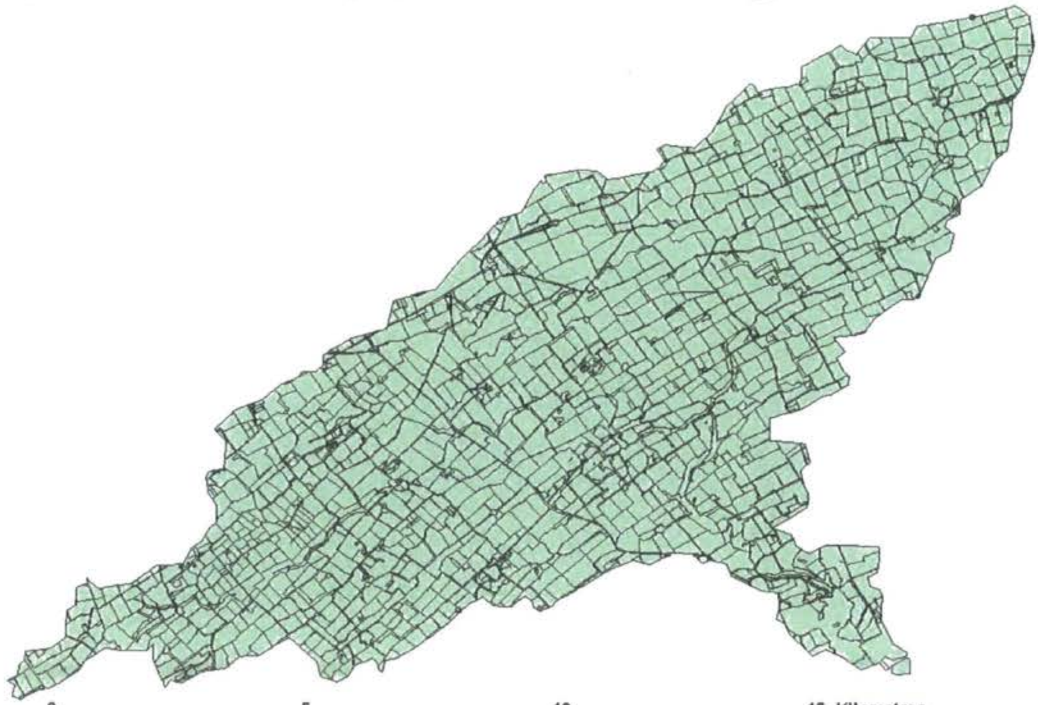
Making corrections to a base layer is a time-consuming but very necessary process. ArcGIS has a 'snapping' facility whereby the end-point of one line segment is moved to 'snap' to the end-point of an adjacent line segment if it is within a user-defined 'snapping tolerance'. However, care must be taken when setting the snapping distance: if this distance is too small snapping cannot occur; if the distance is too great, vertices snap to the wrong end-point. By using trial and error with the snapping distance, approximately 30% of the errors were corrected on the drainage layer. However, the remaining 70% had to re-digitised by hand in ArcGIS, using the OS 1:50000 colour raster image as a guide. At the same time, isolated segments of water features were removed and names (where known) were given to each of the watercourses in the catchment. The layer was 'cleaned' and 'built' to remove excess segments and build the topology of the layer, enabling correct flow directions to be assigned to the water course. From an original dataset comprising 3118 line segments, 287 segments remained. The resulting drainage coverage is shown in figure 5.8 below.

Figure 5.8 The drainage layer, 'cleaned' and 'built'



Correcting the layer with the field boundaries was more difficult. The automated snapping environment was tried but there were few corrections noted. This meant that wherever there was an error, a new polygon had to be digitised. Although this can be done by hand, corrections can only be made from a reliable information source. The OS 1:25000 paper map (Explorer series 339) published in 2000, was used to identify mis-matches between field boundaries and areas where the digital version appeared to have significant errors, e.g. the white areas and very large fields from the previous image, but this method relies on scrutinising both the digital and paper images. In the absence of an automated process, polygons were drawn into these 'spaces'. However, many of the remaining errors could not be identified until ground truthing and the remotely sensed image established where they existed. Ground truthing (described in section 5.3 below) was carried out during the winter and summer of 2002 / 2003 and corrections made to the field layer (figure 5.9 below). However, with nearly 2500 polygons (fields) in the layer it is likely that there will still be some errors that have not been detected.

Figure 5.9 The field boundary layer, 'cleaned' , 'built' and 'clipped' to watershed



In addition to the two base layers, further layers were constructed. These include:

- The catchment boundary, to which the field layer is clipped;
- Roads and tracks;
- Settlements.

5.3 Data collection in the Leet catchment

5.3.1 Ground truth data for land use

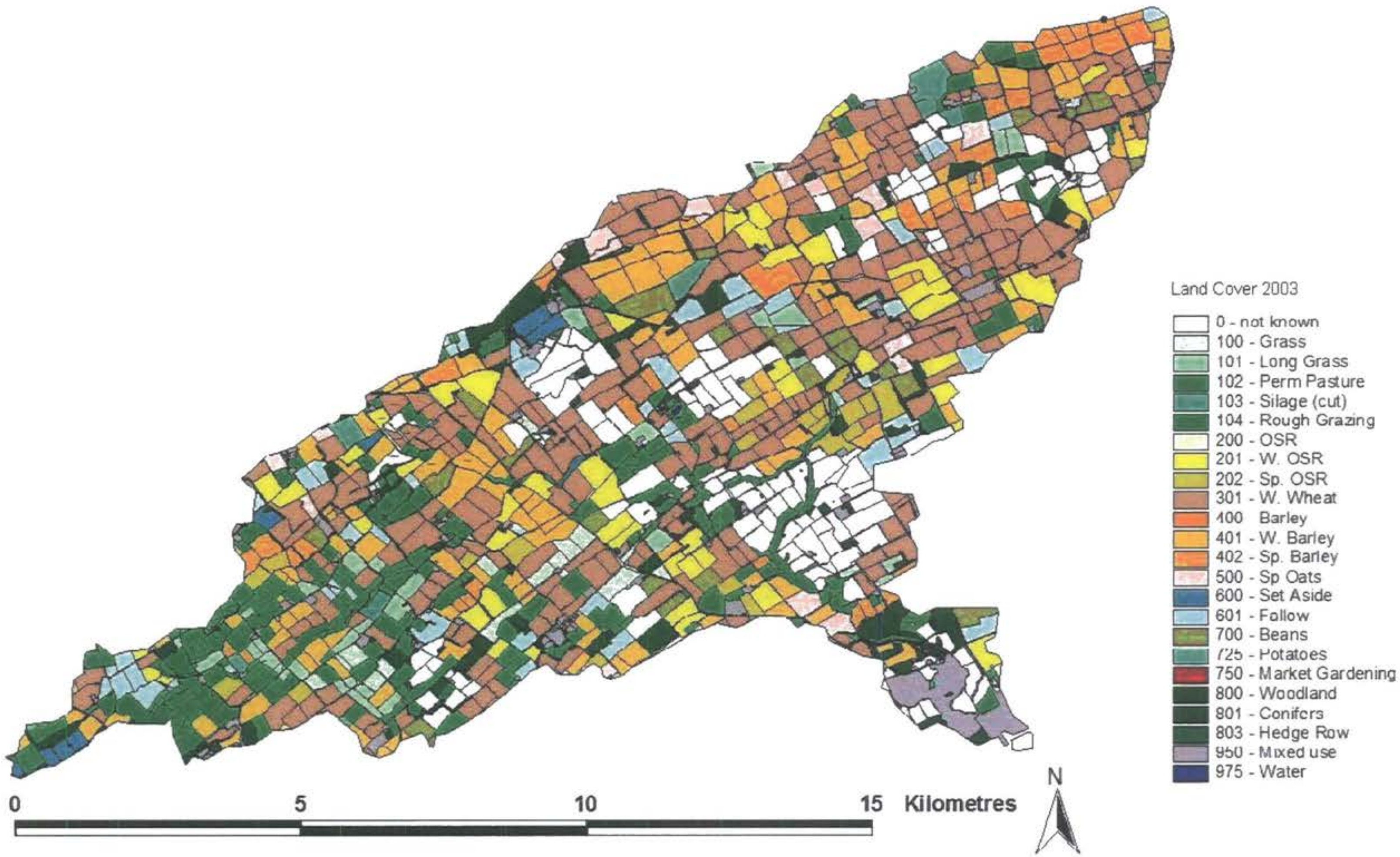
The research requires precise land cover maps to model land use change scenarios. It had not been possible to collect sufficient ground-truthed land cover data during the 2002 growing season, but a complete ground survey gathered data for the 2003 growing seasons. The study site was visited several times to collect data. A printed version of the GIS field layer was used as a base map for noting land cover field by field. At the same time field boundary changes were noted on the paper map and adjustments were made to the digital layer.

The optimum period for collecting data on arable crops is late June to mid-July. During this period there are significant differences in growth stage to allow reliable identification of each crop. Prior to this, immature crops such as winter wheat, spring barley and oats can look very similar as they have not developed their seed heads sufficiently. The following characteristics for each of the crops grown in the catchment were noted:

Table 5.1 Crop characteristics late June to min-July

Winter wheat	Bright green; immature growth stage; tall, established vertical seed head; tractor tramlines evident in fields.
Winter barley	Light to mid brown; mature crop; close to harvest, well established drooping bearded seed head; tramlines may be evident.
Winter oilseed rape (osr)	Pale green; flowering period over; developing seed heads; dense field coverage.
Spring barley	Bright green, similar to w.wheat; immature growth stage; established drooping, bearded seed head; dense field cover.
Spring osr	Distinctive yellow flowering stage; dense field cover.
Spring oats	Bright bluey-green; immature growth stage; established open seed head; appears to 'shimmer' in a breeze; dense field cover.
Permanent pasture	Very short grass; usually with traces of animal waste; livestock often in fields.
Ley grass	Long, lush vegetation; but some fields have already been cut for silage – these look dry - NO animals grazing these fields.
Set-aside	A variety of shrubby vegetation; often brown; fields look neglected.
Potatoes	Large leaved; growing close to ground on ridges; may still be in flower (white or purple) obvious furrow between ridges; may be growing under polythene.

Figure 5.10 The land cover map 2003 (compiled from manual field survey)



These descriptions and the ground survey enabled a land cover map of the catchment to be constructed for 2003 (figure 5.10 above). However, some gaps still appeared in the completed map, which demonstrates the problem of access to all parts of the study area for classification purposes, indicating why other methods of land cover classification were necessary.

5.3.2 Water quality data

SEPA provided a long-term data set of water quality information for 12 sites across the catchment, mainly for the period 1987 – 1998 which has been described in Chapter Three. However, the 'gap' in data from 1998 to the present time meant there was some uncertainty in the current water quality of the catchment. In addition, responses from the farmers' survey indicate that more than 75% think agricultural activities are not a significant threat to water quality, stating they do not use excessive fertilisers (see section 4.2.6). It was therefore important to assess the current water quality to establish any links between farming practice and water quality. Further monitoring would also provide an up-to-date data set to validate modelling and a base for encouraging any necessary farming practice changes. The monitoring was carried out at the same sites used by SEPA from October 2002 to September 2004; ensuring continuity of data. The interval between each sample varied, depending on season and other research commitments. The aim was to collect samples weekly during the winter months, reducing to fortnightly then monthly during spring and summer. The location of these sites has been shown in figure 3.7, and described in Chapter Three.

Data gathering comprised collecting two 50ml vials of water, recording measurements of width, depth and velocity of the watercourse, and making notes of general conditions and characteristics at each site. Equipment for collecting water samples included an acid-washed bucket for sites where water depth was more than 50cm. At sites where water depth was less than this, the sterile 50ml vials were used directly in the watercourse to collect the sample. The vials were labelled with a site identifier and the date of collection. Prior to collecting the water sample the equipment was rinsed three times in the watercourse. Where the bucket was used to collect a large sample of water, the 50ml vials were rinsed in this sample (water discarded back to the watercourse), all 50ml vials were filled to capacity, sealed and stored in a cool box until returned to the University. A pre-printed sheet was used to record width, depth and velocity of the water-course. Velocity at all sites was recorded using a velocity meter At most sites, the narrow width and shallow depth made it possible to stand in or at the side of the water-course and record measurements with a tape measure and metre ruler. At sites KR008 and KR009, the depth of water prevented this so a weighted rope marked at one-metre intervals was used to measure width.

On return to the laboratory, one sample from each site was frozen (to act as a back up in case of mishaps with the working sample), the other was refrigerated until ready for analysis. The sample was then analysed using a Dionex 500 ion chromatograph to determine NO_3^- concentration. The results from the water quality analysis were collated for use in the INCA water quality modelling and are described in Chapter Six.

5.4 <u>Deriving a precise high-resolution agricultural land use map at the field scale from aerial photography and multispectral remote sensed imagery</u>

5.4.1 Rationale for using RS imagery

A vegetation map that not only distinguishes agricultural land use in terms of arable and pasture, but also seeks to define arable crops and short vegetation in terms of the sowing date and fertiliser input required. Farm management (fertiliser) practices differ according to the type of vegetation grown (wheat, barley, oats, oilseed rape, pasture) and period of planting (winter or spring). Accurate classification of crops and land cover at the field scale is required to identify those vegetation types which occupy particularly vulnerable locations, e.g. adjacent to watercourses. This degree of precision will enable a range of land use change scenarios applicable to real-world situations to be modelled at the farm scale using the export coefficient approach and INCA. In addition, it will provide the base of a land-management decision tool to help the farming community assess the extent to which agri-environment scheme funding can be applied to their own situation.

Acquiring such high quality data is not an easy task. Agricultural census returns from the farming community provide data on an annual basis, but these are only available to the research community as an aggregate figure at the 1km scale so it is not possible to produce a field scale map from these data. All farms are now required to keep records of current land use (including the previous five years). This should be the most accurate data set available, but relies totally on agreement with the farmer concerned, to be prepared to share that information with the researcher. Whilst some farms within a catchment may be willing to participate and share information, others will not. For a very small area, data can be gathered manually in the field by annotating a map and transferring the results to a computer database for later analysis. This requires a trained observer who can identify land cover (e.g. different crop types) and preferably a driver/navigator. Following a procedure described above, the recording can be performed to a high level of precision and at a modest cost. However, spatial scale is an issue. As an area increases in size, so generally do problems of access to remote areas and this can result in observation errors. Time involved in travelling around the site also increase as the size of catchment increases leading to higher costs.

High-resolution imagery such as aerial photography and remotely sensed (RS) multispectral data provide a viable alternative to the above methods. Data are acquired either by satellite, airborne sensors or high specification cameras at a variety of scales (as discussed in Chapter Two). The advantages being that these methods are:

- Unobtrusive;
- Can cover large areas quickly;
- Provides a permanent, digital and true record of land cover.

There is, however, one main disadvantage: high quality optical RS data are limited by weather conditions. Cloud cover prevents accurate interpretation of land use and this can delay data acquisition until a suitable day occurs (i.e. one with an acceptably low level of cloud cover). It was thought that the benefits of RS data outweighed this disadvantage and the research chose to use Airborne Thematic Mapper (ATM) RS imagery, because it is available at:

- 5m pixel resolution, so is suitable for classification at the field scale;
- 11 multispectral bands, so unique spectral signatures of crops can be identified;
- User can specify the period of data acquisition, so that imagery will coincide with optimum differences in the stage of crop growth;
- Specified data can be commissioned from commercial sources (in this case the NERC/ARSF as part of competitive awards scheme).

The methodology for producing a land cover map is described below.

5.4.2 Data acquisition

Under the original proposal, data acquisition was requested to include the whole of the Leet Water and Lambden Burn catchments to take place during June 2002, flight direction from east-west, occurring between 10 am to 12 noon. These requirements were important because this period would coincide with:

- Maximum solar elevation angle – to minimise shadow from vertical structures and minimise possible cross-track illumination effects;
- Significant differences in growth stages of winter and spring sown arable crops – enabling identification of crop types.

However, poor weather conditions during the early summer meant the flight was delayed until 13th July 2002 (Julian day 194) and this would have severe knock-on effects on the analysis of data. Furthermore, due to unforeseen delays in data processing at the ARSF, CDs containing the eight flight lines of digital imagery were not received until late January 2003 and a package of 275 aerial photographs was only received in March 2003. Research training was then required to use new software packages for RS image processing and analysis.

5.4.3 Using aerial photography for land use classification

Aerial photographs at the 1:10 000 scale were used to gain an overall impression of the land cover in the catchment and help classify land use on a field-by-field basis. The advantages of aerial photography for classification are that:

- Specialist computer software is not required;
- A manual classification procedure does not need expensive specialist training, and can draw on knowledge and experience to differentiate land cover, i.e. the interpreter 'knows' what field boundaries, trees, buildings and roads should look like;
- Classification can be verified by more than one person;
- The high resolution of photographs provides a permanent high quality map resource.

However, this method of classification does have disadvantages:

- There are problems of orientating the photograph and base map – e.g. associating the correct field on the photograph and base map;
- It relies on detailed written/verbal descriptions of differences in vegetation types for accurate classification;
- Classification is subjective, trainer's description of a particular land cover type may not mean the same to the trainee, e.g. what is 'pale green';
- Variation in colour reproduction of similar vegetation types can lead to mis-classification;
- Data acquisition must be at the optimum period in growth stage to differentiate vegetation types;
- Very small features cannot be easily identified;
- Classification over large areas is very time consuming.

However, mid-July is within the optimum time period to identify a range of crops as there are significant differences in most of the crops grown in this area.

Winter barley is almost fully ripe, and its appearance on the ground ranges from light to mid-brown, indicating very little moisture in the plant. By contrast, spring barley is immature and varies from dark to mid-green, the 'beards' on the grain heads are well developed and this can add a sense of texture to the image and some fields may have an undulose sheen to them as ground level breezes move the crop. Winter wheat is still growing vigorously, which having a high moisture content, shows up as dark green. In addition, although it is densely sown, tractor 'tramlines' are very visible due to the vertical stalk and seed head of the crop. Oats are also growing vigorously, but being less densely sown than wheat, with a loosely formed seed head results in a bluey haze to the bright green colour on photographs. On the ground oats are very distinctive but can be difficult to distinguish from spring barley on photographs because they are at a similar stage of maturity. Winter oilseed rape at this stage has passed flowering, the seed heads are beginning to ripen and lose moisture; its pale green colour allows it to be differentiated from other green crops such as wheat, spring barley and oats. Spring oilseed rape is still in full flower and therefore displays its distinctive bright yellow colour.

The catchment has a large proportion of land under grass. Much of this is permanent pasture. These fields are close cropped and often appear to have small 'knobbly' features representing rough surface texture. The high resolution of the aerial photographs makes it is possible to identify livestock on such fields with a magnifying glass. Ley grass (a crop cut for silage) is also difficult to distinguish. Generally, uncut ley grass is mid to dark green, but can have bare patches if it was poorly sown and can be mistaken for wheat or spring barley. However, some of these fields may have recently been cut and so may appear as bare ground, making it difficult to distinguish from a field in the first year of set-aside where vegetation is poor. Set-aside is very difficult to distinguish from a cut field of ley grass or a field in first year fallow, as there are often several different vegetation types present depending on how long the field has been out of arable production. However, this may not be crucial to the research, as these fields will not have had a fertiliser application and therefore are not categorised as high risk.

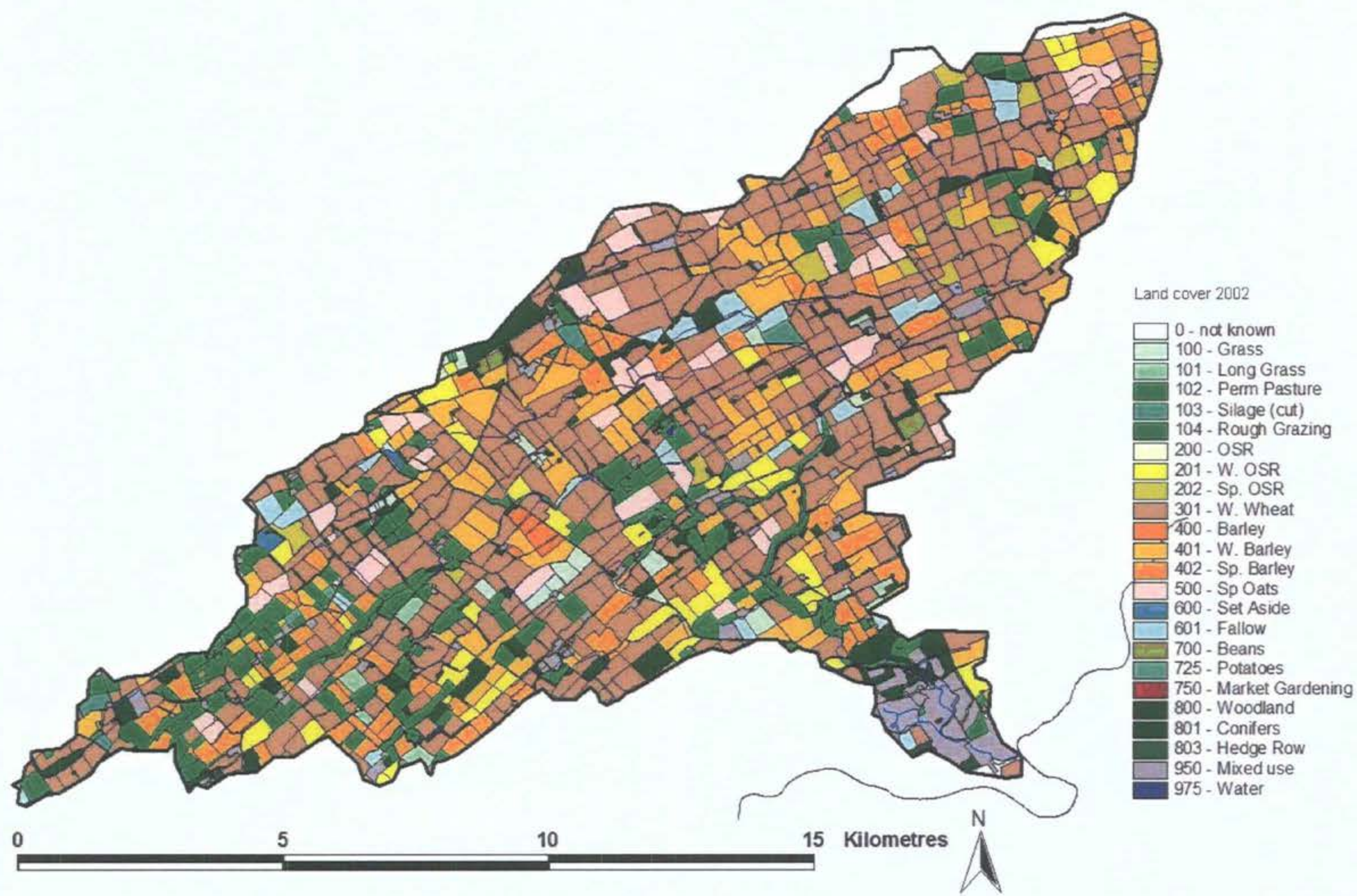
To assess the precision of using aerial photography for land cover classification, a group of colleagues were trained to identify vegetation types using the descriptions above. A sample of 50 fields that had been verified by farmers' records was compared to the trainee's classification. This resulted in classification precision of 87.2% (table 5.2 below). Following the same protocol, the whole of the catchment was then manually classified from the aerial photographs (figure 5.11 below). To overcome the problem of mis-classification, the two 'trainees' who achieved the most accurate classification scores were used to corroborate the identification of difficult fields.

Table 5.2 Precision assessment of aerial photography classification

Trainee no.	Correct identification	Percentage
1	44	88
2	46	92
3	45	90
4	37	74
5	46	92
	Average percentage	**87.2%**

Although manual classification can produce a high precision map, the process of classification is very subjective. Identification of particular land cover types on large areas can be a problem as the classifier becomes tired or loses confidence in their own judgement. In this case, the trainees found some crops very easy to identify. For example, spring sown oil seed rape was still bright yellow, wheat had very distinctive tramlines but the classifiers found it difficult to distinguish spring barley from oats as both crops were quite similar in shades of green, with few other 'clues' to help them. It was also difficult to be precise if a field of ley grass had recently been cut as this could have been a field in the first year of set-aside. To overcome these problems, RS multi-spectral data was then used to see if as precise or better classification of land cover could be achieved by taking advantage of the significant differences between the arable crops described above.

Figure 5.11 Land cover 2002 classification from aerial photography



5.5 Data preparation for RS image analysis

The NERC/ARSF provide customised software (AZGCORR and AZEXHDF) to automatically geo-correct and to convert raw image data into formats suitable for post processing in commercial RS image processing software such ENVI 4.0[31]. The NERC software also embeds header information on the images detailing the coordinates of each flight line matching the OS National Grid system for use in GIS packages such as ArcGIS.

Initial processing of data was carried out on a SUN Microsystems UNIX platform, full details of which are included in Appendix 4. This enabled the flight lines to be prepared for visualisation, further processing and analysis in the software packages ENVI and ArcGIS. However, it was found that data on one of the CDs was corrupted and this had to be re-ordered causing a further delay to analysis.

When the data could be viewed in ENVI, it was necessary to examine the images to assess the degree of correction required and to what extent interpretation and analysis would be possible. Problems of illumination differences and cloud cover are highlighted in figure 5.12 and 5.13, Flight lines two and three have been overlapped to demonstrate the difference in the illumination in the imagery caused by changes in flight direction (from west to east, for flight line 02 and east to west in flight line 03). This is not, however, purely a visual effect; where this effect occurs within a field the spectral signatures of the land cover differs.

In figure 5.13, this image shows the effect of cloud cover. Flight line 08 appears much darker than flight line 07. Although some field boundaries can be made out, others are virtually obscured. The ***Enhance*** tool was used, but the image could not be enhanced sufficiently to show more detail and enable crop identification.

[31] ENVI - software for the visualization, analysis, and presentation of all types of digital imagery (http://www.rsinc.com/envi/)

Figure 5.12 Effects of flight direction on illumination

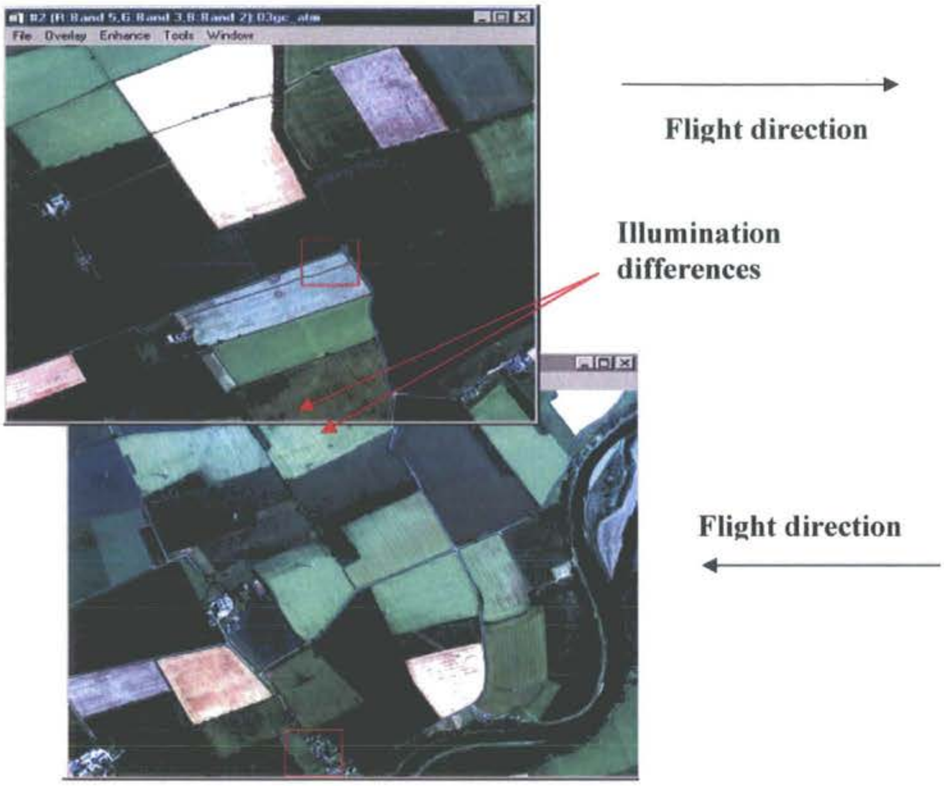
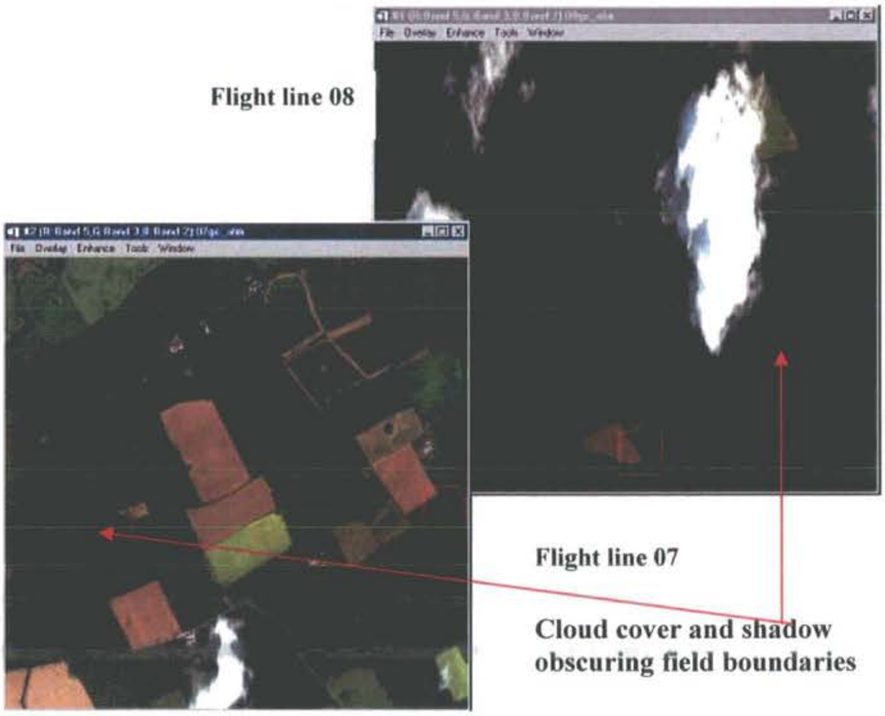


Figure 5.13 Effects of cloud and shadow on digital imagery



5.5.1 Correction and rectification of images

The study requires all images to be used across different software packages and with a variety of data sets from other sources. To achieve compatibility, full geo-correction to the British National Grid co-ordinate system was required. The level of accuracy required to geo-correct the image file to match OS map co-ordinates is a root square mean (rms) error of less than 1 pixel size (5m x 5m).

Using the **Map Registration Tool** within the ENVI software allows ground control points (GCPs) to be matched on the digital image to a second image that is known to be correct. The vector shapefile from Digimap, OS land line data, comprising arcs from feature code 0030, was used to construct a layer of the field boundaries, and overlaid onto the flight line image enabling the existing distortion to be viewed (figure 5.14 below).

With the image file open in ENVI and the vector shape file open in ArcGIS, 24 easily identified matching points, for example, the centre point of a cross-roads, or the sharp boundary corner of a field were selected to find the XY co-ordinates in ArcGIS. These were then manually entered into the **GCP Selection Box** as E N (Easting / Northing) co-ordinates. A wide distribution of points was selected across the whole of the flight line to ensure as good a match as possible (figure 5.15 below).

When all 24 points had been entered into the **ENVI GCP Selection Box**, the file was saved and the '**warp file**' command used to generate a new, fully geo-referenced image. To check whether the geo-referencing had succeeded, the vector shape file of feature code 0030 was overlaid onto the new image. As figure 5.16 shows, the process was successful although in computational terms it was time-consuming. A similar process was carried out on all eight images.

Figure 5.14 Digital image overlaid with vector layer field boundaries

Figure 5.15 Using GCPs to geocorrect digital image

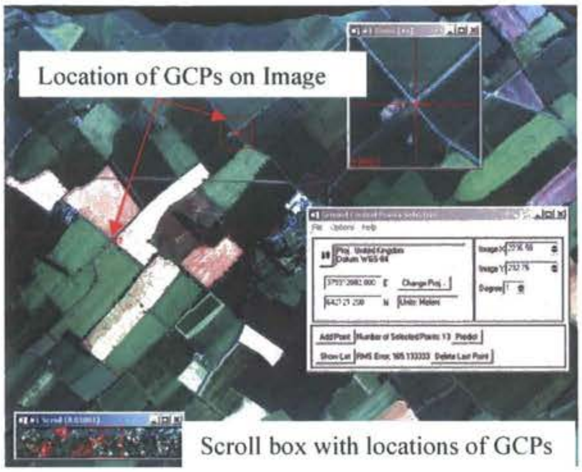


Figure 5.16 Image warped to GCPs

The final stage of geo-correction involves accounting for atmospheric distortions. Solar radiation reflected by the surface, travels through the atmosphere both before and after interaction with the ground before its detection by the ATM sensor and during this period, radiation is affected by particles in the atmosphere, mainly through scattering and absorption. This influences the amount of electromagnetic energy that is measured at the sensor. Although this is reduced under clear sky conditions, atmospheric attenuation still affects the quality of the ATM data and therefore the value recorded for a given pixel may not be representative of the ground-leaving radiance at that point.

Where temporal ranges of images are to be compared, it is essential for atmospheric distortions to be removed. As part of gathering ground-truthed data, a GER 1500 spectroradiometer can be used to measure field reflectance for a series of predetermined target materials taken at the same time as the flight occurs. At the same time GPS co-ordinates of the targets are collected to locate them on the image map later. However, in this study, only one RS data set had to be used, so atmospheric correction was not so important. This was most provident as a series of problems were encountered at the time of data acquisition.

As mentioned above, the expected flight day for data acquisition was delayed due to very poor weather conditions. Eventually one day's notice of an expected flight date (Saturday 13th of July 2002) was given. The GPS was not available for that weekend as it was in use by another project. This meant that accurate positioning of the targets would not be possible, so easily identified points, such as cross-roads or very large fields growing different crop types were substituted.

A mid-day time slot had been requested, but the flight took place earlier in the morning than expected and there was a delay in travelling to the study site from Durham. Furthermore on arrival at the study site on the morning of the flight, the roads within the study site were closed off due to the 'Jim Clarke Scottish Road Rally' taking place. This meant that the pre-planned locations could not be visited to take radiometric readings of the target surfaces. It was not possible to make a return journey to the study site within a few days of the flight as this researcher was due to go abroad for 3 weeks leaving early on 14th July, the day after the flight.

The data acquisition occurred early on in the research project and at that time the importance of ground-truthing had not been fully realised. Further field visits to the study site were not made until late October (after harvest), by which time it was too late to collect adequate data for ground-truthing. Some land cover information was gathered during farmers' interviews, and fortunately this addressed the full range of farming types across the catchment.

There were other problems associated with data acquisition. The proposal for RS data requested a time slot close to midday. This would have reduced the amount of shadow from vertical structures that obscured accurate boundaries between features. However, the flight took place at 08.00 hours, which resulted in considerable low-angle shadow making it difficult to determine field boundaries and fully classify the land cover within that field. During the morning, considerable cloud cover developed which reduced image clarification; not only through the cloud itself, but also from the shadow cast. Four of the flight lines covering the upper Leet were particularly affected, and this would significantly reduce the quality and quantity of data for use in the modelling process.

5.6 Land cover classification from multi-spectral digital data

Land cover classification on digital image data can be performed in a qualitative way by visual interpretation of a spectral subset of that data either in black and white or in colour. Alternatively, the spectral information of a group of pixels in a parcel of land can be classified into land cover types by an appropriate algorithm. This poses the key question: Can difficult land cover types be distinguished by their spectral signature?

Multispectral data images are acquired simultaneously from the same geometric point, but in different parts of the electromagnetic energy spectrum termed bands. Table 5.3 shows the band characteristics of the Daedalus 1268 Airborne Thematic Mapper instrument (compared to those of the more well-known Landsat Thematic Mapper instrument). The ATM records data in 11 wavelength bands corresponding to the following range in the spectrum (wavelengths in nanometres). Multi-spectral bands are viewed using specialized software either individually in black and white or by selecting three of the available bands and displaying one band as blue, one as green and one as red (an RGB composite).

The optimum visual combination varies with the spectral response of the target. Using an RGB composite image comprising bands 5, 3, and 2, demonstrates a 'natural colour' image. Figure 5.17 below, shows most vegetation types in the fields as a variety of shades of green. In this image it can be difficult to distinguish different crop types by eye. However, better visual contrast can be achieved with a 'false colour' image.

Table 5.3 Wavelengths of ATM band sensors

ATM Band	Equivalent Landsat TM band	Spectral wavelengths	Mid-range point	Spectral range
1		424 - 448	436.0	Blue-Green
2	1	469 – 518	493.5	Blue
3	2	522 – 601	561.5	Green
4		594 – 635	614.5	Red
5	3	627 – 694	660.5	Red
6		691 – 761	726.0	NIR[32]
7	4	754 – 924	839.0	NIR
8		897 – 1027	962.0	NIR
9	5	1600 – 1785	1692.5	SWIR[33]
10	7	2097 – 2391	2244.0	SWIR
11	6	8400 - 11500	9950.0	TIR[34]

This type of image is often used in land cover classification as the colours displayed use a combination of visible and infrared bands to help distinguish different vegetation and surface types. Combinations of NIR, red and green bands (see table 5.3 above) in a false colour image can be used to find the 'best' visual appearance. Examples of these combinations are shown below. In images using ATM bands 7,3,2, (figure 5.18) or the NIR and SWIR bands 8,9,6, (figure 5.19), bright red areas represent high infrared reflectance, corresponding to healthy vegetation, either under cultivation or along rivers. This is because healthy vegetation reflects IR radiation much more strongly than it does green radiation. Slightly darker areas typically represent native vegetation (often coniferous forest). In figures 5.18 and 5.19 below, water is shown as very dark or black, and areas where there is very little moisture, such as built up areas and roads, are also easily distinguished by their light colour. RGB compositions such as these are, therefore, good for identifying a range of surface cover including growth stages and moisture content of different types of vegetation. For example, the fairways on the golf course with its very short grass, are easily identified in the false colour images as they show up as a very pale colour, and the fields on the right hand side of the image illustrate a range of arable crops including wheat, barley (winter and spring sown) and oilseed rape.

[32] NIR – Near Infrared
[33] SWIR – Short Wave Infrared
[34] TIR – Thermal Infrared

Figure 5.17 Natural colour image bands 5 3 2

Figure 5.18 False colour image bands 7 3 2

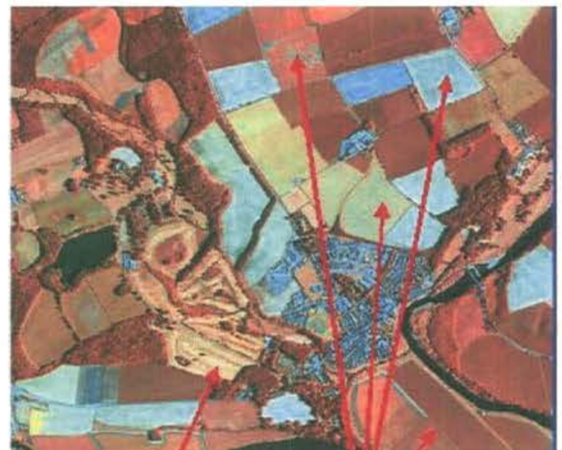


Figure 5.19 False colour image bands 8 9 6

Although visual interpretation and classification is useful for identifying general differences between vegetation types, more precise classification can be achieved by examining the spectral signature of vegetation types and using either unsupervised or supervised classification techniques in image processing software.

5.6.1 Unsupervised classification techniques

Unsupervised classification techniques, such as K-Means[35] or Isodata[36], provide a rapid means of identifying clusters of pixels that belong to spectrally separate categories. Unsupervised classification is a useful technique as it can indicate specific parcels of land that will produce good quality data set. These can be used as regions of interest in training sets for further classification, such as supervised methods. In addition, this process should help to indicate how many land cover classes can be distinguished spectrally.

However, the initial use of these two methods to identify pixel clustering, indicated that many of the land cover classes required for the precision mapping are **not** spectrally unique (see figures 5.20 and 5.21 below). For example, areas of woodland are shown as multicoloured speckles, indicating a wide range of values in the spectral signal without significant clustering. Other land cover classes are also spectrally complex, demonstrated by the ranges of colours displayed within field boundaries. Without prior knowledge of the actual land cover it is not possible to allocate a category to these fields. In addition, although the water bodies (a lake and the river) have been identified, there are also clusters of pixels identified as water,

[35] K-Means unsupervised classification calculates initial class means evenly distributed in the data space and then iteratively clusters the pixels into the nearest class using a minimum distance technique. Each iteration recalculates class means and reclassifies pixels with respect to the new means. All pixels are classified to the nearest class unless a standard deviation or distance threshold is specified, in which case some pixels may be unclassified if they do not meet the selected criteria. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached (source: ENVI online help).

[36] Isodata unsupervised classification calculates class means evenly distributed in the data space and then iteratively clusters the remaining pixels using minimum distance techniques. Each iteration recalculates means and reclassifies pixels with respect to the new means. Iterative class splitting, merging, and deleting is done based on input threshold parameters. All pixels are classified to the nearest class unless a standard deviation or distance threshold is specified, in which case some pixels may be unclassified if they do not meet the selected criteria. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached. (source: ENVI online help)

but are in fact shadows. This indicates that unsupervised classification, rather than being inaccurate, is too precise. The unsupervised classification process is identifying many more categories of land cover than the number of land cover types that are actually present. This is not surprising as there will be small scale variations in the growth stage of similar crops across the whole of the catchment. This is related to several factors. Within a single field, the extent of growth and maturity of the crop and therefore the variation in spectral signature can be the result of available soil moisture, fertiliser application and even sowing density of the grain. Larger variations in the spectral signature of similar crops in different fields will mainly be associated with the date on which that crop was sown; even within a single farm, sowing cereal crops may be spread across a period of three to four weeks, and this will therefore affect the extent of maturity.

Unsupervised classification has shown that in most cases the range of spectral values found within individual field boundaries is too great to form a single classification of that land cover type and that a sensible classification for the whole of the dataset is not possible using this method.

Figure 5.20 K-Means unsupervised classification

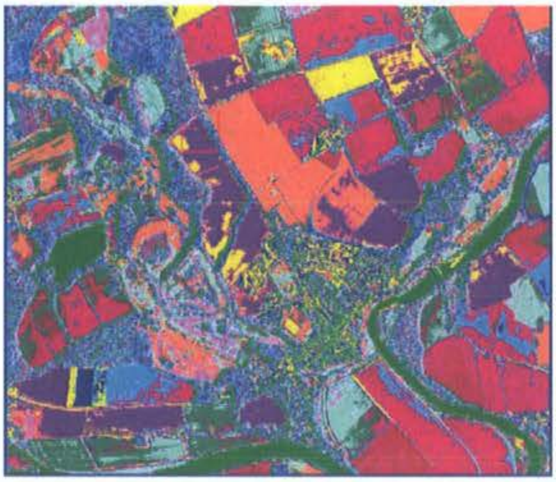
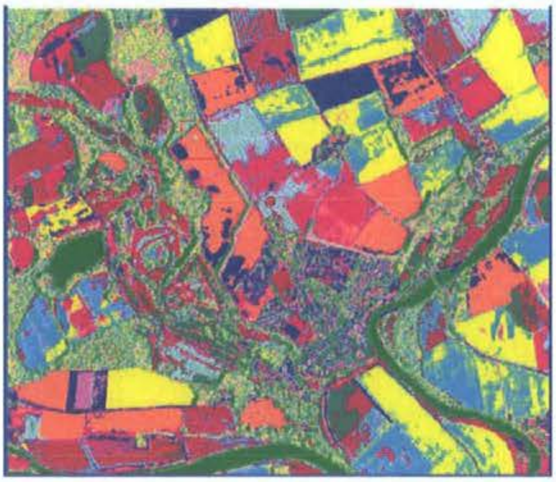


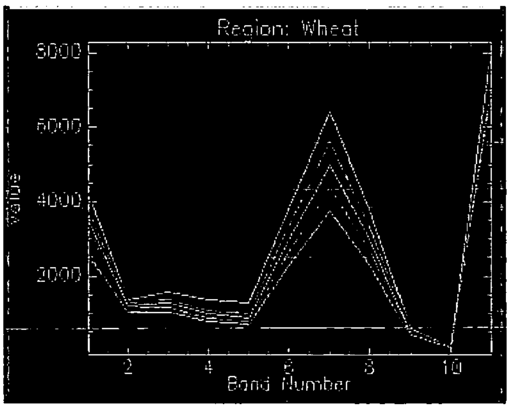
Figure 5.21 Isodata unsupervised classification



5.6.2 Supervised classification techniques

A solution to the problem where there is too much variation in a class is to use supervised classification techniques. This method requires training sets of user defined 'regions of interest' (ROIs) to extract statistics of the spectral signature for each vegetation type. These statistics are based on a maximum likelihood classification[37] (figure 5.22 below illustrates statistics for wheat[38]), computed from the spectral mean of the ROI representing the training region of the class, and provide information on the range of wavelength values in each band. This has the advantage that a small subset of the whole data set can be used to derive a unique signature of the defined land cover that can then be used to classify the whole area.

Figure 5.22 Spectral signature and wavelength statistics of wheat



Region: Wheat [Red] 5953 points

Band	Min	Max	Mean	Stdev
1	2560.648193	4190.427734	3469.436254	229.021240
2	1053.436035	1355.561646	1211.040482	70.575142
3	1032.629028	1581.605103	1271.398604	108.647930
4	773.017151	1348.569458	978.524437	95.773282
5	685.384155	1265.653931	881.261876	94.718148
6	2283.536621	3776.063232	2985.363938	358.984114
7	3741.829346	6429.747070	4973.635936	620.625569
8	2305.218506	3771.810059	3029.384102	326.292888
9	363.701263	575.557068	432.858519	24.584593
10	74.493141	96.471840	84.914370	3.358150
11	7037.094727	8091.779785	7174.040797	42.936923

In the first attempt to run the ***maximum likelihood classifier*** (MLC), the aim was to classify 12 land use types. Each training area was selected to be representative of the category to be classified and have a minimum of 200 points to obtain a satisfactory spectral signature (figure 5.26 below).

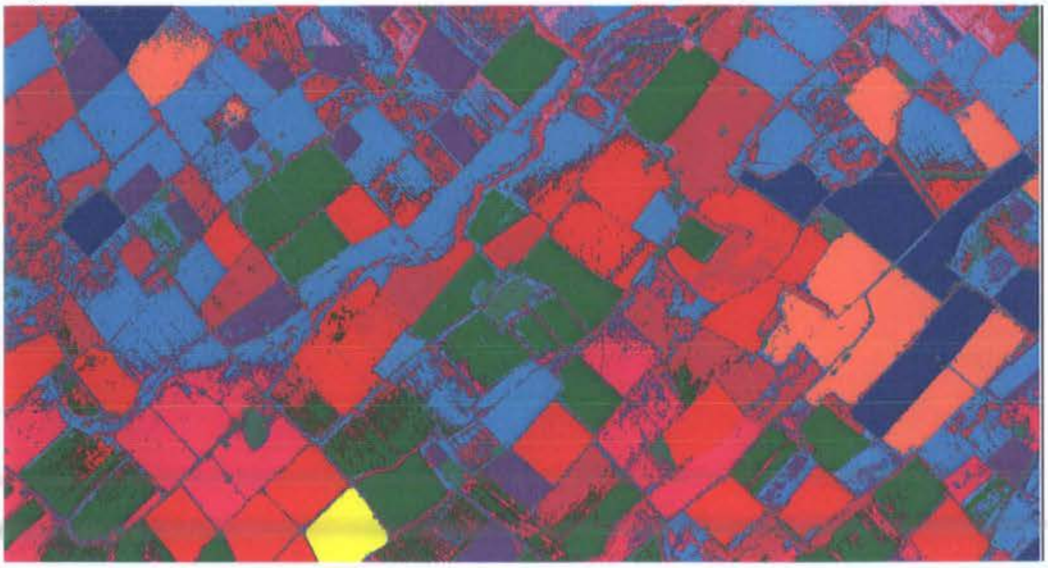
The MLC 12 training areas produced a result that identified the land cover in some fields with a high degree of accuracy. Figure 5.27 shows that almost all field boundaries have been identified, indicating there are spectral differences at field margins. However, there are still cases of mis-classification.

[37] Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class.

[38] In the band statistics example below, ENVI generates a false precision of six decimal places. In any calculation these can be ignored, using whole number only.

Figure 5.26 Selected training ROIs for use with maximum likelihood classifier

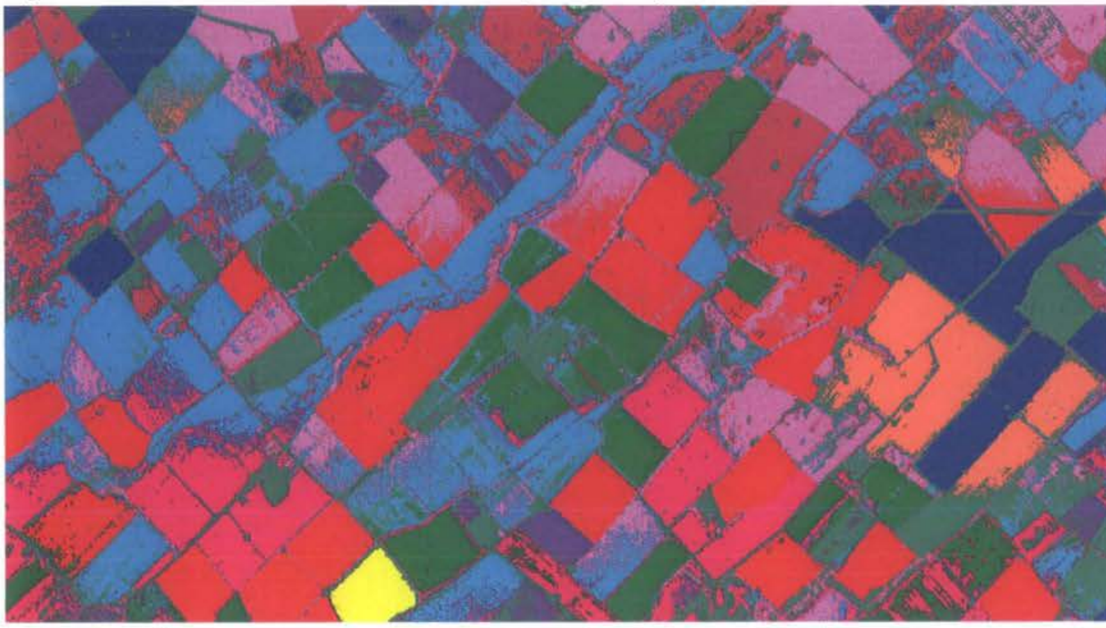
Figure 5.27 Result of maximum likelihood classifier (first run)



Buildings (sea green) have generally been accurately identified with a small error where a recently constructed pipeline has cut through a field, and one large field has been classified as 'buildings'. Spring OSR (Coral) and winter OSR (yellow) have clearly been identified without error. There was only one field in the subset identified as oats (aquamarine) and the classification has not indicated any others so it may be assumed that this is correct. Although there are good classifications of winter wheat (red), spring (green) and winter Barley (blue) in some fields, in others the spectral signal is confused and large areas have shown up as rough grazing (cyan) or woodland (maroon). In general, permanent pasture (magenta) is identified quite well, but in some places this is confused with rough grazing. Stubble (purple) is another category that is creating difficulties in classification. This, however, is not surprising as stubble may include many different surface characteristics. Some fields could be long-term set-aside with different types of rough vegetation at different stages of growth and maturity.

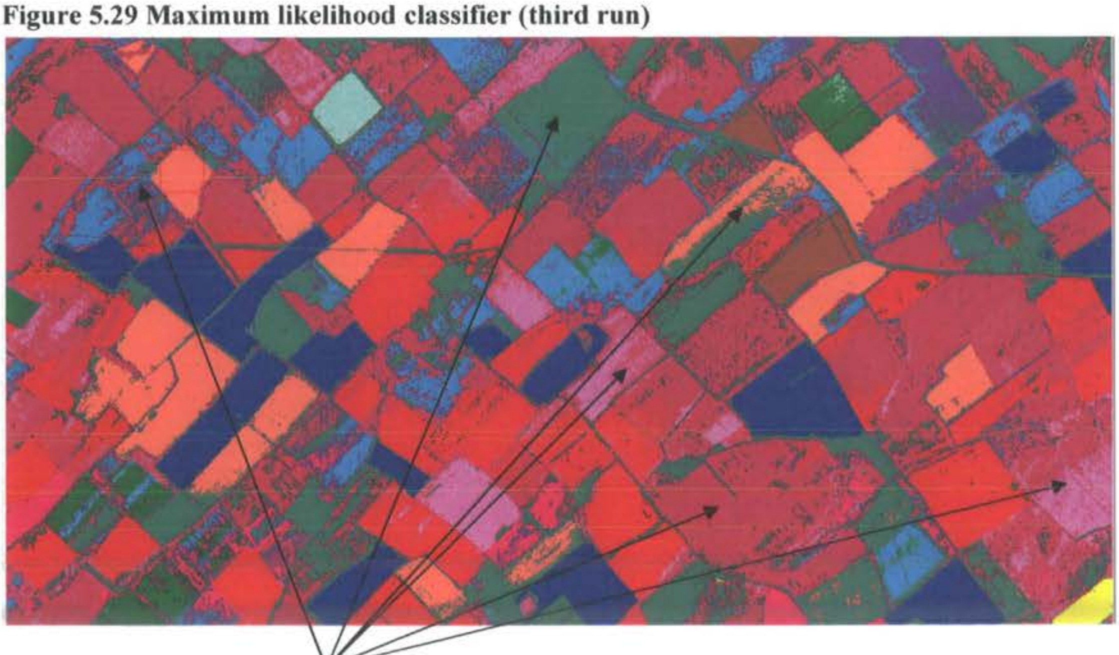
The first result of maximum likelihood classification was quite good. However, in an attempt to improve the accuracy, further training areas were added to the subset ROIs for the most difficult areas to be classified: permanent pasture, rough grazing, and conifers. An additional training area for winter wheat was also added to try and force the erroneous classification of buildings into a vegetation type. Small areas of tarmac were added to the buildings category to see if this would improve the classification. The result (figure 5.28 below), of the second test show some improvements in reclassifying permanent pasture (cyan) but there has been a loss in accuracy in identifying winter wheat (red) and stubble (purple). This was probably due to the subset image being too small and the range of values in each spectral signature was now too high, i.e. the ranges of values for land cover type overlap with those of another, which prevents the separation of land cover types.

Figure 5.28 Maximum likelihood classifier (second run)



A third attempt to improve classification accuracy was made using training sets from the whole of the flight line rather than just a subset. However, as the section in figure 5.29 indicates, this failed to show significant improvements in accuracy. There is still significant confusion in fields of winter wheat, and many arable fields are classified as woodland in error.

Figure 5.29 Maximum likelihood classifier (third run)



It was thought that these errors were caused by cross track illumination effects. The edges of images had not recorded the same spectral information as the centre of the image. It was therefore decided to mosaic all the flight lines together and then perform classifications on one large image. Although this would have the disadvantage of increasing the computing time to process each classification run, it was hoped the improved accuracy would outweigh this.

5.7 Mosaicing images for improved classification

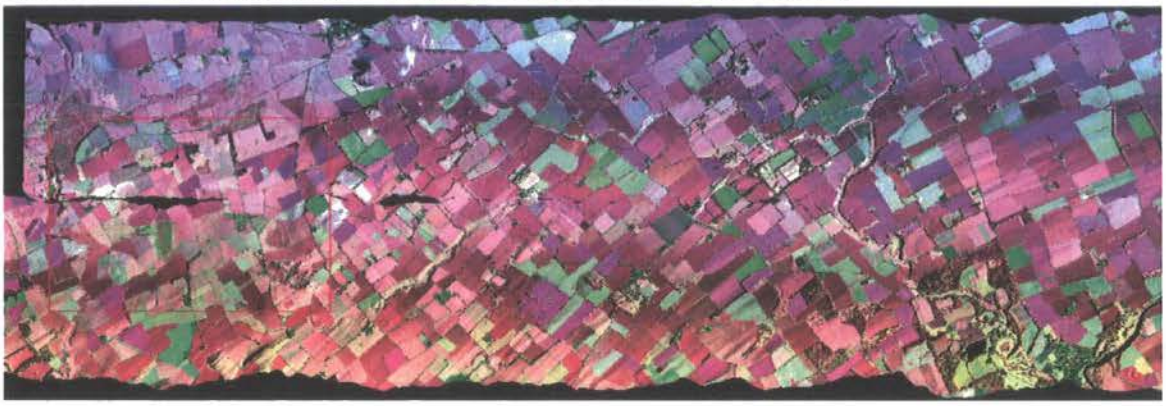
Data covering the whole of the study catchment comprised eight overlapping images. To produce a meaningful land cover map of the study area it would be necessary to mosaic all the images. With the software package ENVI 4.0 it is possible to join adjacent images that either have the same geo-referenced coordinates, or by pixel location. All images covering the study area had previously been geo-corrected so the former technique was used. The software allows a feathering process that removes image borders and performs colour matching where the two images overlap. Initially images representing flight lines two and four were selected to see if the image overlap was sufficient for complete coverage of a selected area (figure 5.30 below).

5.7.1 Errors encountered

This mosaic test enabled two issues to be highlighted. Figure 5.30 below illustrates the extent of gaps between the alternate images and also that colour balancing does not fully correct for differences in spectral signatures where the images join.

The first problem of gaps could be solved simply. To achieve full coverage, all images would need to be mosaiced i.e. image one to two to three and so forth. However, when this was carried out, the problems with colour matching remained. Figure 5.30 illustrates the extent of colour variation between the lower and top edges of the images.

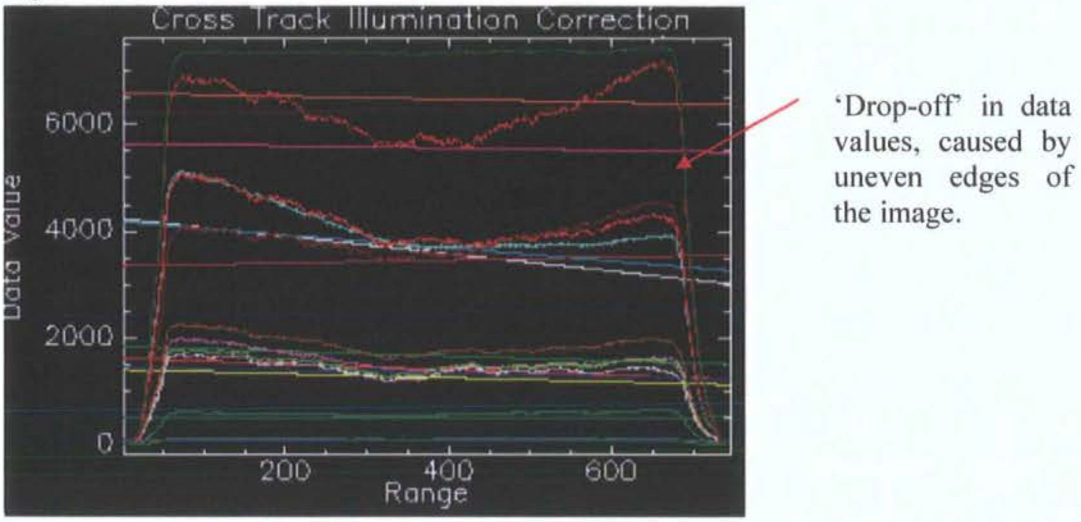
Figure 5.30 Mosaicing images - problems of gaps and colour balancing



5.7.2 Cross-track illumination variations

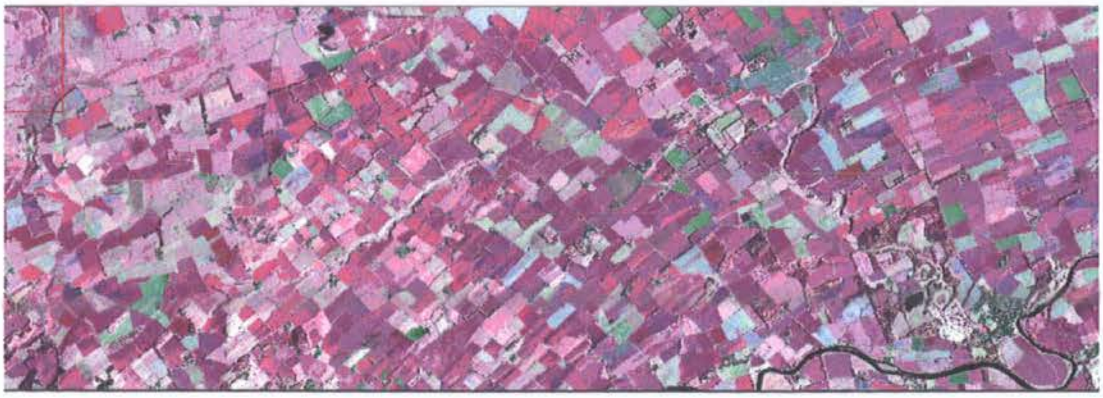
The colour variation is related to cross-track illumination. The main causes of cross-track illumination differences are a result of instrument scanning, or other non-uniform illumination effects at the time of data acquisition. These can be caused by differences apparent in ground reflectance due to sun-scanner-terrain geometry and radiative path-length variations. The apparent differences occur because the aircraft scanner is flown at low altitude with a large across track scan angle and there is slight movement (wobble) in yaw, pitch and roll of the aircraft during flight. This results in an uneven edge to each of the flight lines as can be seen in figure 5.30. In the colour matching process, ENVI software uses the pixel values from the overlapping lines of each image to apply colour matching. However, the uneven edge results in some 'missing data' which is assigned a pixel value of 0, and therefore this edge is not representative of the whole of the image. This is confirmed when the data values for each band are displayed graphically (figure 5.31 below illustrates data for flight line 1). The horizontal axis represents the number of data lines in the image (approximately 675), and the vertical axis the spectral range of each band. As can be seen, the data values in each spectral band 'drop off' sharply at the beginning and end of the range of lines; within the range of 0 – 50 and 625 – 675 lines. To overcome this problem, the lines from the edges of each image with missing data (the black areas at edge of each image) were trimmed using an image sub-setting routine to remove the data values causing the problems. The software then calculates a new mean for each scan line enabling more precise colour matching between each image file during the mosaicing process.

Figure 5.31 Cross track illumination data values



The mosaicing procedure was then carried out again. Although it is possible to mosaic multiple images in one event, it was found that colour matching at edges performed better when stepwise mosaicing was performed, i.e. image one and two mosaiced together, then mosaicing image three, and then joining image four. It was decided not to include images five to eight, as these images were significantly affected by cloud and cloud shadow and it would not be possible to carry out an accurate land cover classification on those images. The final result of the mosaicing process is shown in figure 5.32 below. All gaps and spectral variations at the edges have now been corrected.

Figure 5.32 Mosaiced image of flight lines 1,2,3,4

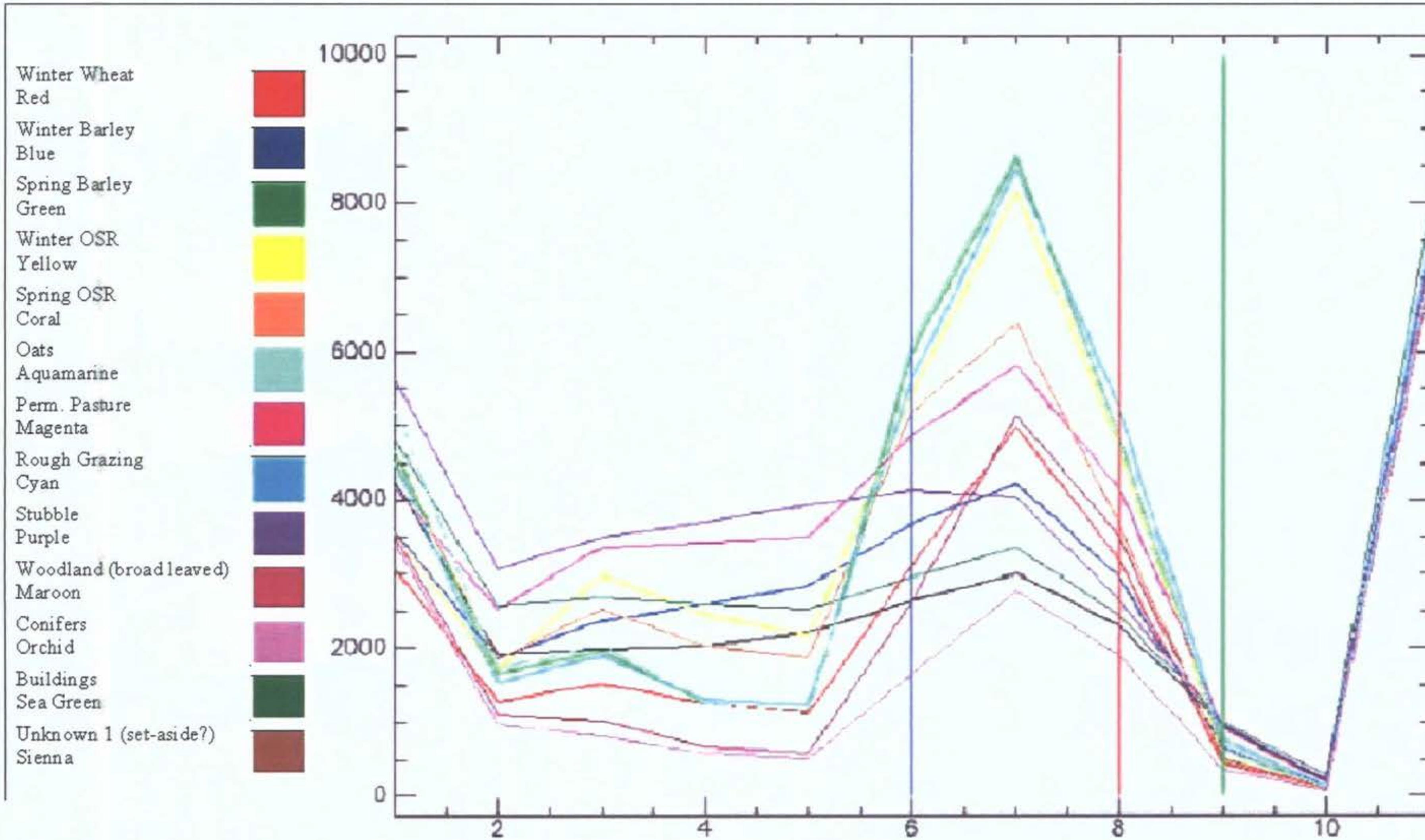


5.7.3 *Assessing spectral separability*

This mosaiced image was used to generate a new set of ROIs with the aim of producing a fully representative set of spectral signatures across the catchment. Figure 5.33 [39] below illustrates the spectral signatures taken from the mean values of pixels within the ROIs of the 12 land cover types. A 13th land cover ROI was added – its true identity was unknown, but was most probably set-aside. From this it can be seen that spectral separability varies according to band-width. For all land cover types, there is very little spectral separability in bands 9, 10 and 11, but separability improves to varying extents in all other bands. For example, in bands 6, 7 and 8 good separability is demonstrated for all vegetation except spring barley, winter oilseed rape, oats and rough grazing. Bands 3, 4, and 5 also demonstrate separability in most vegetation types. The vegetation types that were still green in colour on the ground (spring barley, winter oilseed rape, oats and rough grazing), are spectrally similar in some bands, with some variation in other bands, for example winter oilseed rape can be separated in bands 3, 4 and 5, but spring barley and oats are too similar in these band to be successfully separated. Although it is desirable to separate all crop types, spring barley and oats may have to be combined and regarded as one crop in the mapping process. This is unfortunate as fertiliser practices differ for these two crops and, in the absence of reliable information from the farmers on fertiliser practices in these fields, this will be a limitation of the classification.

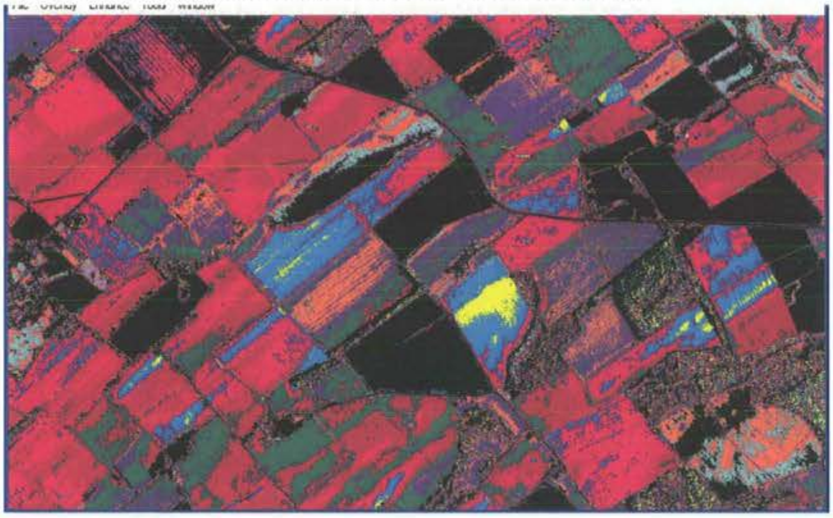
[39] The graph is a screen capture from the software and its poor quality is a result of image stretching to highlight the spectral signatures of each land cover type.

Figure 5.33 Mean spectral signatures of land cover types (ENVI software screen capture)



The K-Means algorithm was tried with the mosaiced image, requesting 12 classes (the number of land cover classes required), at 1 standard deviation. However, the resulting clustering has confirmed that the land cover classes are **not** spectrally distinct. If all the pixels within a field plot are spectrally similar or fall within an acceptable range, then that field plot will show up as a single colour. The more colours displayed in a plot of land the greater variety of clustering occurs. Figure 5.34 illustrates that areas of woodland are shown as multicoloured speckles, and the majority of other land cover classes are confused. In addition, where clustering seems to be distinct at the field scale (the black areas) these are in fact different land cover classes.

Figure 5.34 K-Means algorithm applied to the mosaiced image



Increasing the range of values to 2 standard deviations from the mean did not produce a better result. It was thought that the number of classes requested was too low, therefore the number of classes was increased to a number it was known would be far greater than required, in this case 20. Water bodies were clearly identified, as were areas of buildings and tarmac. Although fields with arable crops were showing some definition, there is clearly some overlap in the clustering of pixel values within the field plots. Woodland posed the greatest range of pixel values and it has not been possible to produce a cluster that defines the spectral range of broadleaved woodland. However, as parcels of woodland can be identified from maps this is not considered to be a significant problem. The software help guide suggests increasing the number of iterations to improve the clustering. The result after ten iterations was not significantly better than the first run. There was a better result with the number of iterations set at 25, but the level of accuracy was still not considered to be acceptable. In addition, the computational time of 25 iterations increased so much (the process taking nearly two hours) that it was thought not to be a satisfactory process.

To make further progress in creating the land cover map, an alternative classifier known as the Decision Tree Classifier was tested.

5.7.4 The decision tree classifier (DTC)

The decision tree is a hierarchically based classifier, which compares the data with a range of selected features (Friedl and Brodley, 1997; Richards and Jia, 1999). The DTC performs multistage classifications by using a series of binary decisions (0 or 1) to place pixels into defined classes, the 0 result is sent to the "No" branch and the 1 result is sent to the "Yes" branch of the decision tree. Division of the pixels into the two classes can be based on either a pre-determined or user defined expression. Each new class is then divided into two more classes based on another expression. This technique has the advantage that many decision nodes can be defined depending on the number of classes required, and these can be interactively edited to improve accuracy. In addition, data from many different sources and files can be used together to make a single decision tree. Formulating the expression for the selection of features is determined from an assessment of the spectral distributions, or separability of the classes. Advantages of the DTC over other supervised classification techniques are that computing time is less than the MLC and, by comparison, the statistical errors are avoided. In addition, the tree can be 'pruned' to refine the parameters of the final image to improve accuracy. However, the disadvantage of DTC is that the level of accuracy does depend fully on the design of the decision tree and the selected features.

The default classification technique for vegetation types in ENVI is the Normalised Difference Vegetation Index (NDVI). This is a ratio between the NIR and Red bands where valid results of the NDVI calculation fall between -1 and +1. The red band records the absorption of red wavelengths by chlorophyll; lower values in this band indicate higher chlorophyll content. The NIR band records reflection of IR wavelengths by the cell structure of leaves, in this band higher values indicate more vigorous growth. Therefore the ratio should be able to distinguish between different land cover and vegetation types by examining the 'greenness' of land cover.

The automatic NDVI function in ENVI is calculated from bands 7 and 5 of the ATM data. Using the ROI statistics already established for the different land covers, a spreadsheet of the mean values was prepared (table 5.4 below). The NDVI ratio was calculated using the formula:

$$NDVI = (NIR - R) / (NIR + R)$$

Table 5.4 Mean spectral values to calculate NDVI

Land cover	Band	Mean	Land cover	Band	Mean	NDVI ratio
water	5	723.595	water	7	404.016	-0.283
buildings	5	2007.208	buildings	7	2378.256	0.085
w-barley	5	3308.289	w-barley	7	4933.973	0.197
stubble	5	2478.547	stubble	7	5091.874	0.345
sp-osr	5	1695.341	sp-osr	7	6364.981	0.579
w-osr	5	1732.669	w-osr	7	8090.525	0.647
p-pasture	5	1218.088	p-pasture	7	6308.788	0.676
r-grazing	5	1236.249	r-grazing	7	6610.349	0.685
conifers	5	677.984	conifers	7	3826.205	0.699
wheat-dark	5	732.918	wheat-dark	7	4764.530	0.733
wheat-light	5	881.098	wheat-light	7	6082.703	0.747
woodland	5	767.006	woodland	7	5546.066	0.757
sp-crops	5	1011.893	sp-crops	7	9086.550	0.800

The DT was compiled from these ratios. The first node separated vegetation from non-vegetation (buildings and water). The binary decision **NDVI > 0.086** allocates a value of 1 (YES), and all values above 0.086 are classified as vegetation. Any pixels with a ratio of less than 0.086 are valued as 0 (NO) and classified as non-vegetation. The next node (**NDVI > 0.199**) separated winter barley from the remaining values by allocating pixels with a value less than 0.199 as NO and therefore classified as winter barley. The remaining pixels are on the YES side of the DT awaiting further sub-division. This procedure was followed identifying each class of vegetation by sub-dividing the pixels at each node (figure 5.35 and 5.35 below).

Figure 5.35 Example of decision tree node construction

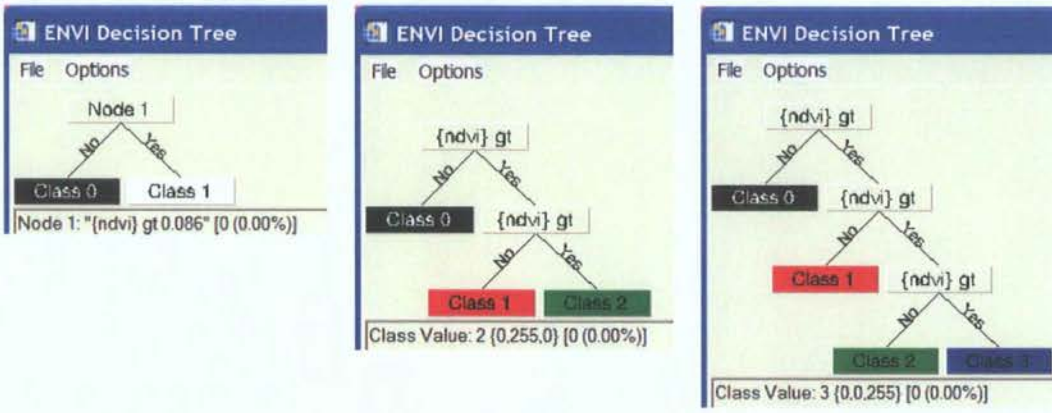
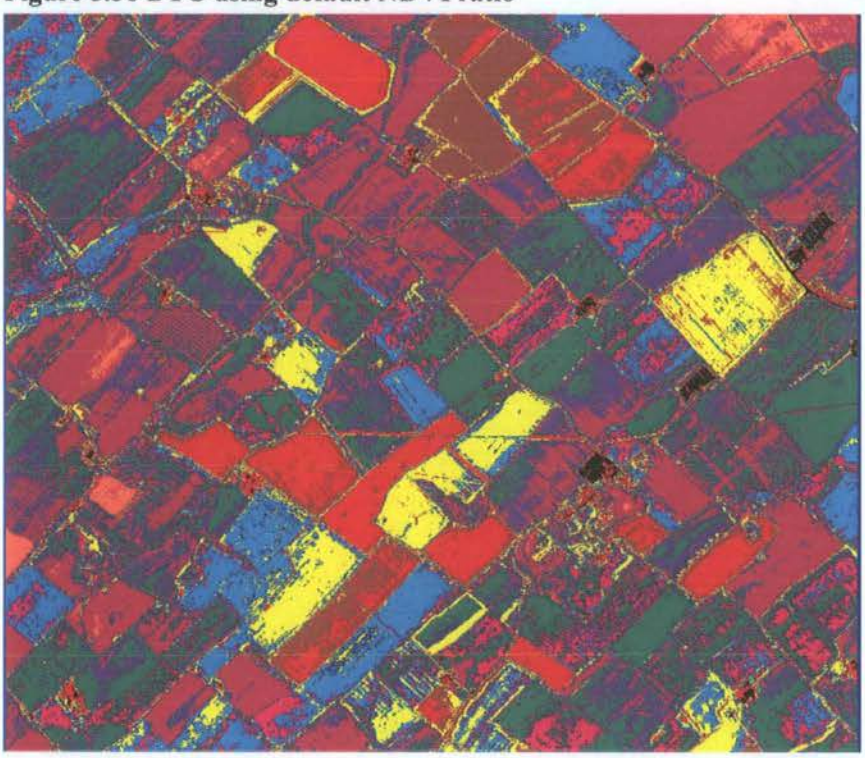


Figure 5.36 DTC using default NDVI ratio



The execution of the NDVI ratio decision tree identified buildings and water course well, but very few fields of arable crops were identified as having a single vegetation type correctly. Figure 5.36 above, illustrates that most fields display a mixed classification. This result was disappointing as great care had been taken with the training set of ROIs to obtain a representative range of pixel values, i.e. selecting fields where there were distinct variations in the visual colour and where confidence of land cover type was very high.

The advantages of the default NDVI decision tree classifier are that it:

- Is a rapid process, once the NDVI values are known;
- Can add as many classes as desired;
- Provides a visual interpretation of the class;
- Enables the NDVI ratio value required for each land cover class to be edited;
- Is a process that is easy to understand.

However there are disadvantages:

- NDVI works on a single value (the mean) in a range of spectral responses;
- It needs great care in determining the 'boundary' between each decision tree node;
- It must have good quality ROIs to calculate statistics.

The conclusion to be drawn from this is that the default NDVI ratio is not satisfactory for identifying vegetation differences apparent from growth stage. This is because non-vegetation land cover types such as water and buildings are spectrally distinct, and can be easily defined in a decision tree classifier. However, NDVI uses a ratio of the **mean** of the NIR and the Red bands, and this does not take into account the full range of values in the spectral signature that identify the small differences in the signatures for arable and in particular, winter and spring sown, crop definition.

Although the result of the NDVI DT had been disappointing, it was believed that the DT classifier could perform well if the expression was composed from user defined values for each land cover type. These expressions would include a maximum and minimum range of pixel values taken from a variety of bands where it was thought spectral separability could be identified. To achieve this, a new set of ROIs were created from a range of targets for each land cover and statistics used to derive the maximum and minimum values were calculated on firstly one then two standard deviations from the mean. The range of values for each land cover were scrutinised to reduce the overlap between land cover classes. The expressions used in this decision tree are shown in Appendix 5, with the resulting map in figure 5.37 below.

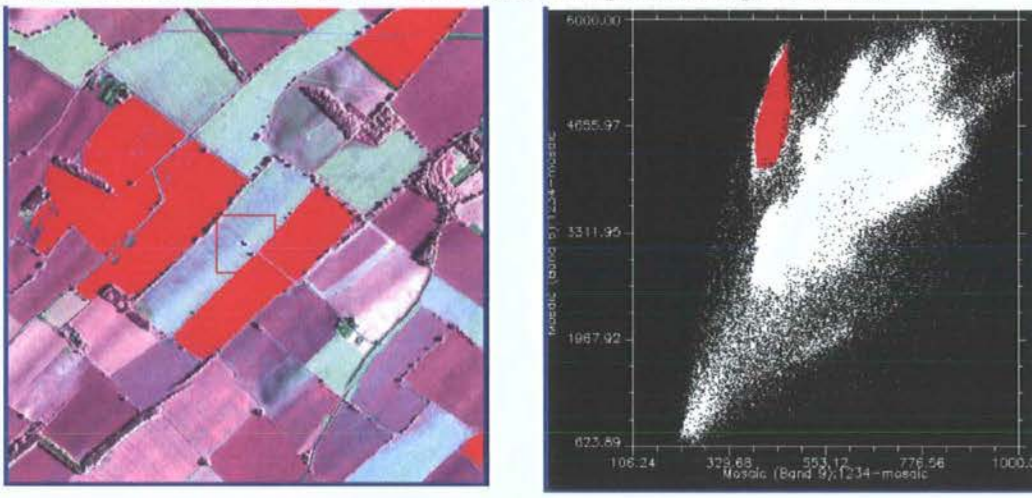
Figure 5.37 DTC with user defined maximum and minimum values on bands 5 and 7

Blank areas demonstrate lack of classification by NDVI ratio

However, using just two bands demonstrates there are still significant errors and gaps in the classification of vegetation types. In addition, the main disadvantage of executing a complete DT with a large number of classes is that the execution time can be quite considerable, taking up to two hours to process. Although a single parameter can be edited, to observe the result the DT has to be executed each time. This can make the classification task overly long, so it was necessary to simplify the execution process.

It was decided to select a single land cover class to make the best DT using different band combinations and ranges of values. If an acceptable result was achieved, this would be saved as a single image layer, then exported to ArcGIS. When all land cover classes had been completed, all the DTs would be overlaid for comparison to the map completed manually from the aerial photographs (figure 5.11 above). The 2D histogram function in ENVI enabled the spectral location of individual land cover classes to be identified. By examining the spread of pixel values in the histograms, clusters were identified, exported as a ROI and matched to location on the digital image. For example, winter oilseed rape is well defined on bands 6 and 9 (figure 5.38 below). Using this technique, the full range of spectral statistics for the winter-oilseed rape ROI were extracted and the expression for the new decision tree developed.

Figure 5.38 2D histogram plot of winter oilseed rape and image definition



This procedure was followed to identify each crop type. However it was found that spring barley and oats could not be identified as different land cover types, so these two crops were combined and called spring-crops. Similar problems were encountered with the different grass types, so rough grazing, permanent pasture and ley grass were combined and called grass. Trial and error to increase or reduce the range of the spectral signature enabled the 'best' land cover classification to be achieved.

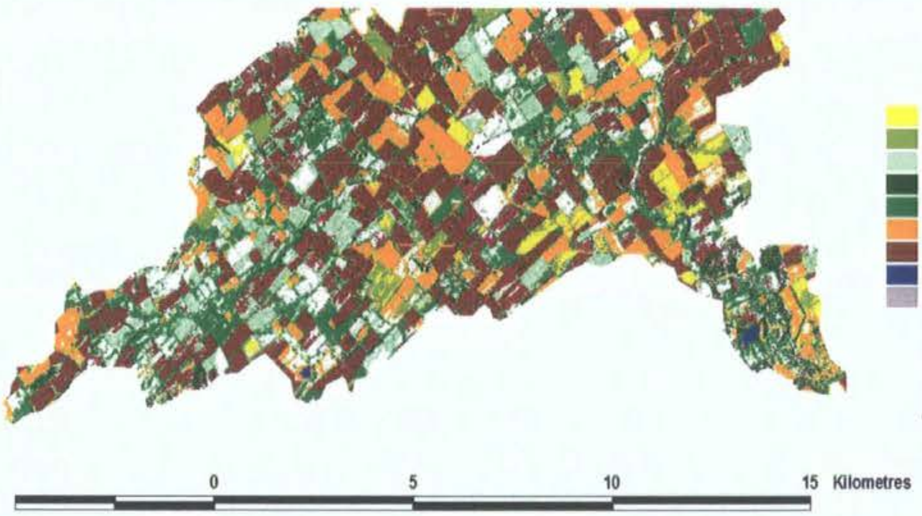
Table 5.5 below shows the expressions used in compiling each decision tree. The resulting images were saved for use in ArcGIS. These images were then exported and converted to ArcGIS shape files for comparison with the land cover map compiled from the aerial photographs and farmers' information (figure 5.39 below).

Table 5.5 User defined parameters for DTC expression builder – based on minimum and maximum values

Land cover class	DT expression
Non-veg	(b5 gt 1200) and (b5 lt 2700) and (b7 gt 1000) and (b7 lt 2000)
Water	(b5 lt 1300) (b7 gt 216) and (b7 lt 2000)
W-wheat	(b9 gt 375) and (b9 lt 500) and (b6 gt 2600) and (b6 lt 4000)
W-barley	(b5 gt 1700) and (b5 lt 3500) and (b7 gt 2135) and (b7 lt 7660)
W-osr	(b9 gt 425) and (b9 lt 450) and (b6 gt 4000) and (b6 lt 5500)
Sp-osr	(b5 gt 1750) and (b5 lt 5000) and (b9 gt 450) and (b9 lt 550)
Sp-crops	(b4 gt 880) and (b4 lt 1300) and (b7 gt 6500) and (b7 lt 10300) (b9 gt 500) and (b9 lt 600)
Grass	(b6 gt 3500) and (b6 lt 5100) and (b8 gt 3200) and (b8 lt 4800) and (b4 gt 1200) and (b4 lt 1400)
Woodland	(b7 gt 2700) and (b7 lt 4000) and (b5 gt 500) and (b5 lt 1000)

Figures 5.39 and 5.40 below indicated that winter wheat and winter barley have been successfully identified. The oilseed rape crops have also been identified, but in some fields the spectral signal still results in some confusion on whether it was a winter or spring sown crop. Although the spring barley and oats can now be identified in one category (as spring crops), there is confusion in separating this from ley grass.

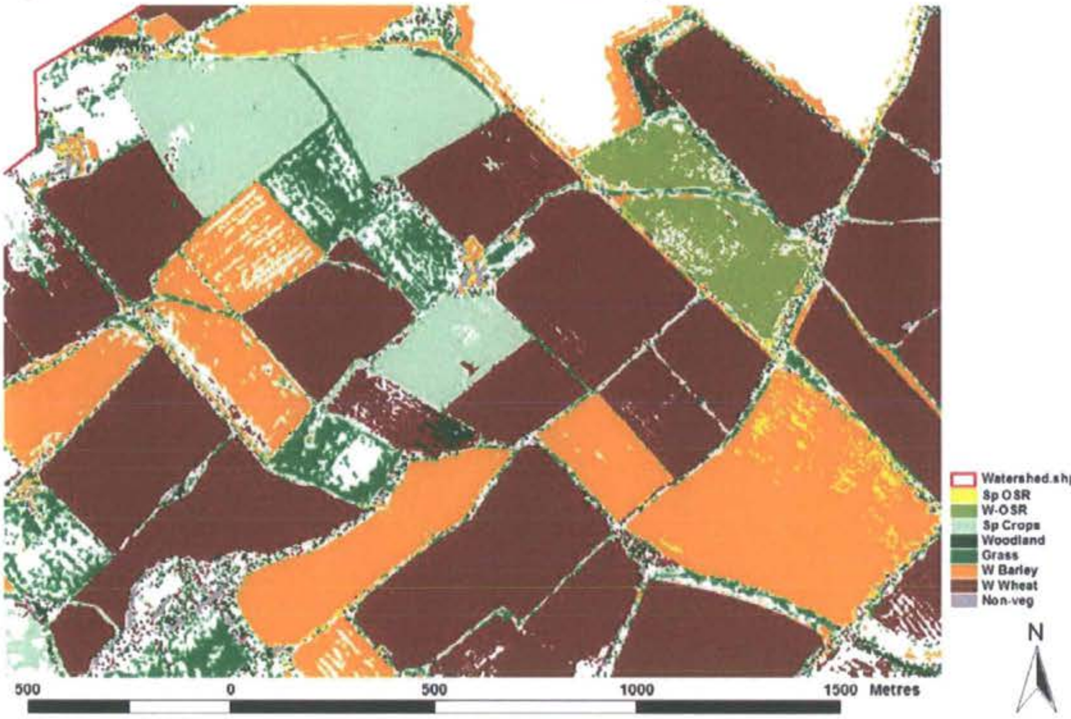
Figure 5.39 ArcGIS image of user defined land cover classes[40]



[40] Areas of white within the boundary indicate no classification has been possible from the user defined expression.

A confusion matrix (table 5.6 below) based on the same training set of fields was used to assess the accuracy of this technique.

Figure 5.40 Selected land cover for field scale accuracy assessment



Blank areas within the watershed, indicate no classification was possible on the given data

Table 5.6 Confusion matrix, field scale accuracy assessment of RS classification

	WW	WB	W Osr	Sp Osr	Sp crops	Set-aside	woodland	Grass	Non-veg	Total
Actual number of fields	19	6	2	0	8	2	3	8	2	**50**
Number of predictions	22	8	2	0	6	0	3	7	2	**50**
Number of correct predictions	19	6	2	0	4	0	3	5	2	**41**
Number of Incorrect predictions	3	2			2			2		**9**
Error occurrence	*Plus 1 pp & 2 sp-barley*	*Plus 2 set aside*			*Missed Sp barley*	*Classified as wb*		*Missed 2 fields*		

The confusion matrix above is based on the DTC identifying sufficient pixels within a whole field to assign a one of the 12 user defined land cover group. Non-identification is indicated by blank areas. A valid identification is assumed where more than 75% of the pixels record the same land cover. The matrix above indicates that the user defined DTC has correctly identified 41 of the 50 fields in the training sample. However, it is noted that the spring crops were the most difficult to identify correctly. Although it had been believed that a sufficient spectral signature range had been used in the DT expression, oats were correctly identified but spring barley was not picked up. Two of the eight fields were not classified at all and two were classified as winter wheat. The spectral range for winter wheat correctly identified all 19 fields with this crop, but in addition, included one field of grass and two of spring barley. Grassland also proved to be difficult to fully identify, with some areas being missed. These errors were not unexpected as the spectral range for each group had to be restricted to reduce the overlap between different classes, but in particular fields, the growth stage of that crop may have been more similar to another crop than was expected. A result where there has been no classification is better than one with an erroneous classification. In these cases the 'blank' fields can be compared to the aerial photograph or digital image for extra clues and then a land cover class be assigned. However, a precision of 82% has been achieved and therefore the technique was used to classify the whole of the catchment.

The use of remote sensing technology has demonstrated that a land cover map can be produced with 82% accuracy. However, to achieve this result has required sophisticated software, a range of classification techniques, expert interpretation and considerable time. It is felt that while other remote sensing techniques such as fuzzy classifiers might produce a better result, to test this would be beyond the full remit of this research. However, it would be worthwhile pursuing this as part of another research project. The production of the land cover map is a small part of this research which is required in modelling land use change scenarios. If further time and training had been devoted to this, then the successful outcome of the next stage of modelling would have been jeopardised.

5.8 Summary results of the natural science methodology

From these methodologies it has been shown that manual land cover classification ground survey alone can miss large areas of the catchment due to access to remote fields. Manual classification from a combination of aerial photography and ground truthing can produce a map with an 87% precision on a small sample of fields. This can be scaled up to the rest of the catchment providing an efficient method of collecting accurate data in a small catchment. The precision of the combined remotely sensed imagery and ground truthing was comparable to this at 82%. However, in this study, the use of RS imagery for land use classification had to be limited to the Lambden Burn sub-catchment and lower Leet as cloud-cover and cloud shadow over the upper reaches of the Leet obscured the surface detail preventing these areas to be classified. Furthermore, in preparing the digital data for use in a GIS great care is needed to geo-reference the images to real world co-ordinates to make the data compatible to the national grid reference system and the vector layers previously constructed.

Unsupervised classification methods on the multispectral data identified spectrally distinct surface features such as water bodies, buildings and tarmac as well as field boundaries. However, arable crops and in particular woodland produced complex spectral signatures where clustering of pixel values in each land cover type overlap. This prevented a precise land cover classification. However, by combining supervised classification methods to identify training areas with the hierarchical decision tree classifier, it has been shown that user-defined expressions drawing on different combinations of pixel values in more than two bands can provide unique signatures to differentiate major crop types and in particular the winter and spring sown crops.

The advantage of using RS data compared to aerial photography is that a larger land area can be classified using the same training set with relatively little extra computational time. However, determining the best training set is a very time-consuming process, and would only be more efficient than the use of aerial photographs where very large areas of land cover need to be classified. Furthermore, RS can only be really effective if cloud-free data can be acquired at a time when there is sufficient difference in the growth stage of vegetation types to affect the spectral signature. Given the variable nature of the British weather during the summer months this is a significant limiting factor on the use of RS data.

Producing the land cover map discussed in this chapter has been a key objective of this research. In Chapter Six, the map is used to contextualise water quality data in the catchment. The land cover of 2002 then enables land use change scenarios at the field scale and specific to the Leet Water catchment to be modelled and evaluated. In Chapter Seven, scenarios are taken further by applying these data to the funding opportunities, and to what farmers believe they can do to meet the water quality standard required by the NVZ regulations and to the overall aims of the Water Framework Directive.

Chapter Six:

Modelling water quality and land use change scenarios

6.1 Modelling water quality

In this chapter thematic maps are used to contextualise the water quality problem in the Lambden Burn and Leet Water. Two approaches to modelling water quality are applied to the catchment and the results discussed. The export coefficient approach (Johnes *et al.* 1996; 1997), and the INCA water quality model (Whitehead *et al.* 1998; 2001) are examined to determine the extent to which these models can predict the impacts of land use change scenarios such as:

- Implementing fixed width grass buffer zones to all the water courses;
- Changing arable land use to grass or woodland;
- Reducing fertiliser inputs to existing land use.

6.2 Mapping water quality

6.2.1 Water quality maps

The results of water quality spot measurements taken at gauging stations on the Lambden Burn and Leet Water from October 2002 to August 2004 are tabulated in Table 6.1 below. These data build on the findings of previous water quality monitoring by SEPA illustrating that nutrient pollution from agriculture continues to be a seasonal problem in the catchment (previously described in section 3..1.3). Data confirm that generally nutrient losses are higher during the winter months, the average and maximum losses being 7.9 and 31.1 mg/l NO_3-N; and lower during the summer months with average and maximum losses being 4.7 and 12.3 mg/l NO_3-N.

To illustrate the extent of nutrient loss risk in the catchment, the spatial distributions of NO_3-N mg/l concentrations have been mapped in ArcGIS. Sample maps to illustrate summer and winter pattern are shown in figures 6.1a and 6.1b. A further selection of maps are included in Appendix 6 as figures 6.1c-6.1t and are described below.

Table 6.1 NO_3-N spot measurements October 2002 – August 2004

SITE_ID	OCT_22_02	NOV_6_02	NOV_13_02	DEC_18_02	DEC_28_02	JAN_8_03	JAN_22_03	FEB_8_03	FEB_19_03	MAR_3_03	MAR_19_03	APR_17_03	MAY_13_03	JUN_23_03	JUL_7_03	AUG_18_03	SEP_24_03	OCT_29_03	NOV_20_03	DEC_4_03	FEB_6_04	MAR_6_04	APR_14_04	MAY_20_04	JUN_23_04	AUG_8_04
KR001	0.0	0.0	0.0	6.8	6.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	5.5	5.4	6.2	4.6	0.0	6.5	6.0	0.0	0.0	7.9	9.5	6.5	6.5
KR002	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	7.3	10.1	7.8	8.2	0.0	0.0	5.8
KR003	0.0	0.0	0.0	0.0	8.2	0.0	0.0	0.0	8.0	6.3	7.1	4.9	0.0	4.4	2.6	3.3	5.1	5.2	7.1	8.7	9.8	9.0	9.0	8.2	8.5	5.0
KR004	10.3	31.1	8.5	7.8	7.3	9.0	6.6	11.1	7.6	6.1	6.9	3.2	8.2	4.2	2.5	3.1	4.3	5.5	8.9	8.5	9.4	9.2	9.1	7.9	4.5	5.5
KR006	0.0	6.9	9.6	9.8	8.1	10.5	7.7	9.1	9.3	8.0	7.7	7.4	7.8	4.0	0.0	0.0	4.8	7.3	8.4	9.2	11.3	10.0	10.3	7.8	1.9	8.8
KR007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9	9.1	4.0	1.9	3.9	2.0	2.6	3.8	5.6	0.0	9.8	9.4	9.3	8.0	0.0	4.9
KR008	7.3	8.0	9.2	9.4	0.0	10.1	7.2	8.6	8.7	7.2	6.9	4.3	3.3	3.5	1.2	1.4	3.6	6.0	7.9	9.2	13.9	9.6	9.6	7.1	5.2	6.2
LR003	0.0	10.3	0.0	0.0	3.8	0.0	0.0	0.0	5.6	0.0	4.9	0.0	0.0	3.3	2.4	4.6	3.8	9.2	0.0	0.0	13.8	7.8	5.6	0.0	0.0	11.2
LR005	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	3.5	0.0	2.7	1.5	1.1	0.3	1.0	2.5	0.0	4.4	13.9	7.3	5.0	0.0	0.0	6.4
LR007	0.0	0.0	0.0	0.0	5.4	0.0	0.0	0.0	7.8	0.0	7.1	0.0	6.9	2.7	1.1	0.1	4.1	3.0	0.0	6.4	12.0	10.9	8.3	7.6	0.0	12.3
LR008	6.7	6.3	6.0	6.3	5.5	6.8	5.0	6.4	6.0	5.1	5.3	3.9	3.2	1.6	0.7	2.8	4.0	4.0	6.9	5.3	13.7	8.3	6.0	4.1	2.5	5.4
LR010	6.0	7.9	7.8	7.6	4.3	8.6	5.8	7.7	7.4	6.0	6.3	4.6	4.8	0.8	0.0	0.2	2.1	6.3	6.0	6.7	11.4	8.5	8.1	5.0	0.6	6.9
LR011	5.7	13.5	7.6	7.7	4.7	8.4	5.9	7.7	7.5	5.7	7.5	4.3	5.9	0.5	0.2	0.2	0.4	7.4	2.7	6.4	11.6	8.3	8.0	4.3	1.5	1.7

* A zero indicates site was not visited on that date

On each of the maps nutrient loss has been categorised as extent of risk in five groups rated as:

Low risk (<5 mg/l);
Medium risk (5.0 – 7.9 mg/l);
High risk (8 – 9.9 mg/l);
Very high risk (10 – 11.2 mg/l) and
Exceeds limit (where the nitrate 11.3mg/l limit was exceeded).

On each of the maps, sites where a measurement was not taken are indicated with a blue dashed line. Figure 6.1a below demonstrates that water quality measurements from July 2003 in each of the sub-catchments are categorised as low risk (less than 5.0 mg/l) except for KR001 where the recorded NO_3-N concentration was 5.5mg/l. However, during the winter months nutrient losses are much higher. As can be seen in figure 6.1b, the data for February 2004 indicate part of the seasonal trend, with much of the catchment at high to very high risk or exceeding the 11.3 mg/l NO_3-N concentration limit.

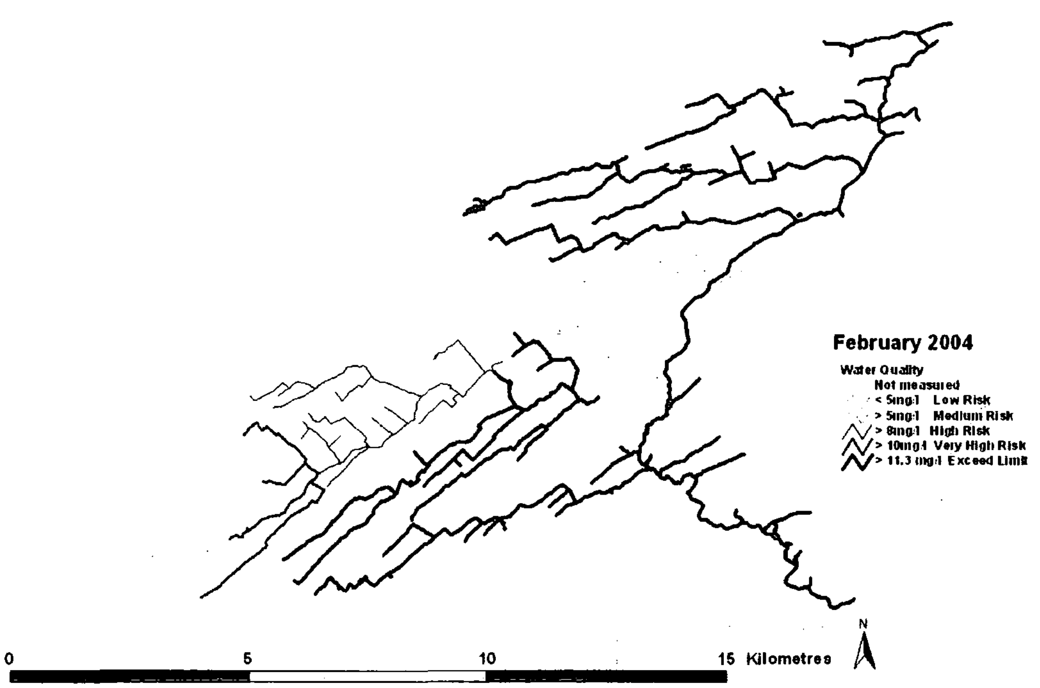
6.2.2 Summary of water quality maps

A further selection of the water quality maps can be found in Appendix 6.1. These illustrate the trend of nutrient loss in the catchment recorded from October 2002 to August 2004. The October 2002 map (figure 6.1c) is of particular interest because the water samples were collected on the 22nd October during a period of high flood. Even though flow was far in excess of normal (figures 6.2a and 6.2b below), the reach above KR004 was at very high risk with more than 10 mg/l nitrate. The other reaches of the catchment that were visited all contained between 5 and 8 mg/l nitrate despite the dilution effect of such a high flow. The land cover map of 2003 confirms that much of the catchment had been sown with winter wheat and oilseed rape. From farmers' interviews it is known that it is common practice to apply a "*small amount*' of fertiliser shortly after planting oilseed rape '*to give it a good start before winter*'"[41]. Much of this recently applied fertiliser would therefore have been available for leaching under such heavy rain at this period.

[41] Italics – farmers' terminology quoted from interviews

Figure 6.1a Leet Water catchment NO_3-N concentrations July 2003

Figure 6.1b Leet Water catchment NO_3-N concentrations February 2004



In addition, the heavy rainfall increased the localised soil erosion where arable fields are adjacent to the water-course, exacerbating the problems of nutrient pollution. The implication of this map alone demonstrates the susceptibility of this catchment to nutrient leaching and soil erosion in heavy rainfall. Monitoring in November 2002 (figure 6.1d) found high concentrations of NO_3-N in the catchment with the sites LR004 and KR004 exceeding the 11.3mg/l limit. Throughout the peak winter months of 2002/3, the reaches within the Lambden and lower Leet continued to be at high to very high risk. Where water quality was sampled, however, the upper reaches of the Leet demonstrated lower concentrations of NO_3-N.

Figure 6.2 KR004 in spate and 'normal' conditions

a) KR004 in spate

b) KR004 normal conditions

During the late spring 2003 period (figures 6.1e to 6.1h), nitrate concentrations were reduced, except at sites KR007 and KR004 which remained at high risk. During the summer months, June to September (figures 6.1k to 6.1m), risk of nitrate pollution was low to medium as crop growth accounted for nutrient take up from the soil. The summer of 2003 was particularly dry and warm, resulting in a very early harvest of arable crops. However, many fields in the catchment were not re-sown until later in the autumn, increasing the level of risk of nitrate leaching in much of the catchment as the soil wetted up in October and November (figures 6.1n and 6.1o). A very wet spring of 2004 increased the risk of leaching and in particular February 2004, found much of the catchment exceeding the 11.3mg/l limit (figure 6.1b. above). The results for early summer 2004 show nutrient losses at low to medium risk. However, a particularly wet August (figure 6.1t) found locations LR003, KR006 at high to very high risk and LR007 exceeding the limit. Overall, these results, demonstrate that this is a particularly vulnerable catchment and should be targeted for implementing agri-environment measures for improving water quality.

The water quality monitoring undertaken during this period brought the SEPA dataset up to date and confirms there were still problems in the catchment and a need to implement strategies to improve water quality. However, due to limitations in the collecting strategy, it was felt the quality of this data set was not as robust as the long-term data. Therefore the SEPA dataset from 1994 to 2000 was used to calibrate the process parameters in the INCA model (section 6.4).

6.3 The export coefficient modelling approach

6.3.1 Introduction to the export coefficient approach

The export coefficient approach has been applied to intensive lowland agricultural systems in the UK (Johnes, 1996; Johnes and Heathwaite, 1997). This model aims to predict the nutrient loading at any site in the drainage network of a catchment as a function of the export of nutrients from each source in the catchment above that site. The model is constructed using the following data:

- Spatial distribution of land use and fertilisers applied to each land use type;
- Numbers and distribution of livestock and human populations in the catchment;
- Input of nutrients to the catchments through nitrogen fixation and atmospheric deposition;
- Export coefficients derived from literature sources and/or field experiments to determine the rate of loss of nutrients from each source to the surface drainage network.

In this research certain simplifications were made due to the lack of experimental data and information available from the whole of the farming community in the catchment.

- Export coefficients were derived from literature sources;

- Farmers' interviews indicated that the maximum rates of fertiliser were being applied so this was assumed for the whole of the catchment;
- The total annual load of nitrogen was expressed as a risk map and modified to identify sections of the catchment vulnerable to leaching.

6.3.2 *Calculating the export coefficients*

The classified 2002 land cover map (discussed in Chapter Five) was used as the base for the modified model. To calculate the extent of risk of N loss, the following equation was used:

$$L = \sum_{i=1}^{n} Ei\left[Ai(Ii)\right] + p$$

(Johnes, 1996)

where:

L	is loss of nutrients;
E	is export coefficient for nutrient source I;
A	is the area occupied by land use type i, number of livestock type i;
I	is the input of nutrients to source;
p	is the input of nutrients from precipitation.

The model incorporated the export coefficient values described by Johnes, shown in Table 6.2 below.

Table 6.2 Export coefficient values

Land cover / livestock	**N export coefficient**
Cereals	12%
Root crops	20%
OSR	30%
Rough Grazing	13 kg/ha/yr
Woodland - hedgerows	13 kg/ha/yr
Cattle	16.2%
Sheep	17%

Source: Johnes 1996

Several assumptions have been made for the Leet catchment. Variation in actual fertiliser application rates were not known for all farms in the catchment, but the farmers interviewed stated they were applying inorganic fertiliser to cereal crops to the maximums suggested in the PEPFAA[42] code (210 kg/ha). For grasslands, the postal survey provided data on stocking levels and size of land holding for the majority of farms. From these an average stocking rate of 2.7 cattle and 10.1 sheep per hectare was assumed. Values of quantities and nutrient status of excreta, obtained from the NVZ documentation on the SEERAD website [43] are shown in table 6.3 below. This enabled an average N loading from cattle of 286 kg/ha/yr, and 90 kg/ha/yr for sheep to be calculated. An input value of 188 kg/ha (average of sheep and cattle) was used in the spreadsheet calculations as it was not known which grasslands were sheep or cattle specific, or how livestock were moved around the catchment as part of a grazing rotation.

Table 6.3 Livestock N loading

Class of Stock	**Total N excreted by one stock unit kg/year**
Dairy Cows	106
Dairy Heifers	58
Calves 6months-1yr	12
Calves 1-2 yrs	47
Breeding Ewes	9
Other sheep	1.2

Nitrogen input from wet deposition was determined by the Wet Deposition Nitrate 2000 map taken from the Centre for Ecology and Hydrology website [44]. For the Merse area of Scotland the map indicates values between 2.8 and 3.4 kg N ha/yr. In the model an average value of 3.15 kg N ha/yr was used to calculate input p [45] for each parcel of land.

[42] Prevention of Environmental Pollution from Agricultural Activities
[43] http://www.scotland.gov.uk/library5/environment/nvzapr.pdf
[44] http://www.edinburgh.ceh.ac.uk/pollution/projects/Dep_ConcMaps.htm
[45] Later correspondence with the Macaulay Land Use Institute confirmed this to be an accurate assumption.

The ArcGIS attribute table for the land cover map provided data of each plot of land in terms of land cover and area. The area (with a default value in m^2) of each plot of land is calculated in the software using the Avenue scripting command:

[Shape].ReturnArea

Six additional data fields corresponding to each part of the export coefficient equation were then added to the table to enable the calculation of total N loss kg/ha/yr:

Hectares	[A] converts default GIS area value to hectares;
Input precip	[p] N deposition for each plot of land (3.15 x ha);
Fert kg ha	[I] maximum rate of fertiliser application for that land cover;
Total fert	[A x I] calculate total fertiliser application for that plot of land;
N ex coeff	[E] the export coefficient for that land cover group;
N loss	[L] the result of the calculation in kg/yr for that plot of land ((E x total fert) + p).

Table 6.4 below illustrates a range of data used in the export coefficient calculation.

Table 6.4 Example of spreadsheet data to calculate N loss at the field scale

LAND_2002	HECTARES	INPUT_PREC	FERT_KG_HA	TOTAL_FERT	N_EX_COEFF	N_LOSS
W. Barley	0.30	0.94	210	63.00	0.120	8.50
Sp. Barley	7.11	22.40	210	1493.10	0.120	201.57
Woodland	0.32	1.01	0	0.00	13.000	1.01
W. Wheat	9.77	30.78	210	2051.70	0.120	276.98
W. Wheat	19.86	62.56	210	4170.60	0.120	563.03
Woodland	0.33	1.04	0	0.00	13.000	1.04
W. OSR	7.41	23.34	210	1556.10	0.300	490.17
W. OSR	8.69	27.37	210	1824.90	0.300	574.84
W. Barley	22.09	69.58	210	4638.90	0.120	626.25
W. Wheat	11.40	35.91	210	2394.00	0.120	323.19
Potatoes	3.26	10.27	200	652.00	0.200	140.67
W. OSR	14.44	45.49	210	3032.40	0.300	955.21
P Pasture	10.68	33.64	188	2007.84	0.050	134.03
P Pasture	6.01	18.93	188	1129.88	0.050	75.42
Woodland	0.08	0.25	0	0.00	13.000	0.25
Set Aside	2.38	7.50	0	0.00	13.000	7.50
W. Wheat	3.59	11.31	210	753.90	0.120	101.78
Fallow	15.23	47.97	0	0.00	13.000	47.97
Sp. OSR	15.04	47.38	210	3158.40	0.300	994.90

The advantage of ArcGIS modelling is that it enables the export coefficient calculation to be performed on a per-field basis. Using the 2002 land cover as a base map provided a spatial dimension of predicted output relevant to the main stakeholder group (i.e. the farming community). Results of the preliminary modelling found the area within the whole of the Leet catchment to be 11,213 hectares. Calculated total nutrient input (organic and inorganic fertilisers) was a little over 2.0 $x^{10^{-6}}$ kg resulting in a total loss of nitrogen to the catchment of 285,540 kg, an average of 25.5 kg/ha/yr. This loss takes into account all land uses including areas of settlement. Although the export coefficient model can include data on human impacts of nutrient inputs/outputs, these have not been modelled here, as this research in primarily concerned with agricultural activities. Table 6.5 below, summarises the results for land cover associated with the main farming activities. Cereal crops are the most significant land cover in terms of area, input and losses of total nitrogen, accounting for approximately 74% of the total land use and nitrogen input in the catchment but approximately 92% of the nutrient losses.

Table 6.5 Nutrient export from agricultural sources in the Leet catchment (2002)

Land cover source	~Area Ha	% land cover	Fertiliser inputs kg	Total export of nitrogen kg	% of the total loss of nutrients
Pasture	1403	12.52	264017	17622	6.17
Rough grazing	121	1.08		381	0.13
Cereal crops §	8302	74	1743427	263168	92.2
Wood & Hedge	530	4.73		1670	0.6
Fallow & Set-aside	333	2.97		1050	0.4

§ *Includes 3 fields of potatoes (9.37 ha) which accounted for nutrient loss of 377kg.*

Furthermore, when the impacts of winter sown wheat and oilseed rape are examined, these account for 47.21% of the total area and ~59% of nutrient losses as shown in table 6.6 below.

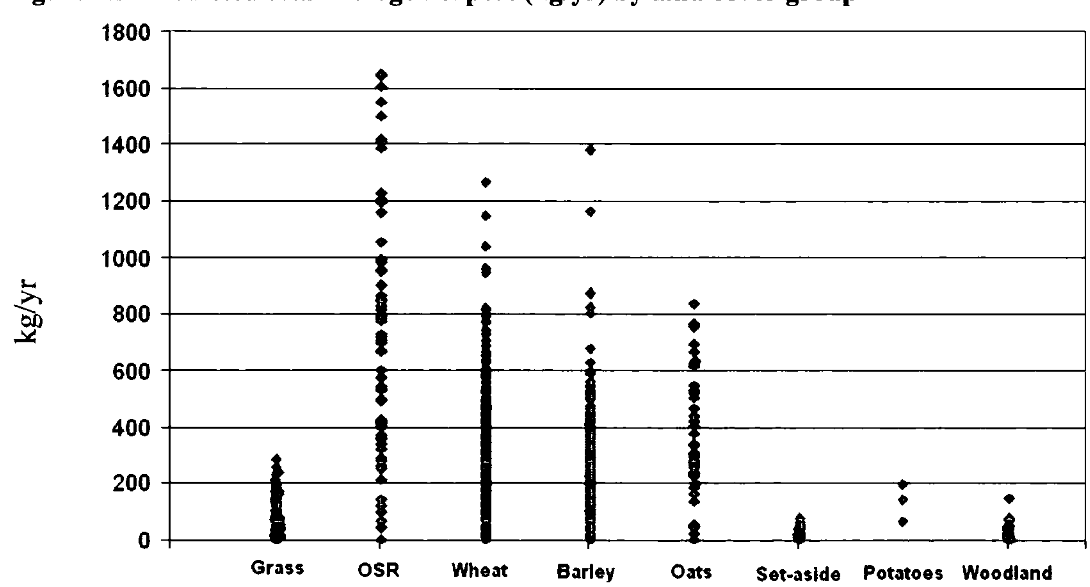
Table 6.6 Nutrient export from winter wheat and winter oilseed rape (2002)

Land cover source	~Area Ha	% land cover	Fertiliser Inputs kg	Total export of nutrients kg	% of total loss of nutrients
W.wheat	4763	42.5	1000261	135736	47.5
W.oilseed rape	549	4.9	115296	35091	12.3

The distribution of these data values is shown on figure 6.3 below. From these results, the main trends observed in terms of total nitrogen loss are that:

- Predicted loss for each field plot ranges from 0 to 1646 kg/yr;
- Potatoes, woodland, grass, and set-aside have the lowest predicted losses;
- Arable crops have higher nutrient loss;
- Highest losses (>800 kg/yr) are on 40 fields growing oilseed rape and wheat;
- A further 170 fields have predicted n-losses of more than 400 kg/yr;
- Oilseed Rape has the greatest variation in range of nutrient loss.

Figure 6.3 Predicted total nitrogen export (kg/yr) by land cover group



These results illustrate the significance of cereal cropping, and in particular the significance of winter sown crops to the problems of nutrient export in the catchment as a whole.

However, describing nutrient export in kg/year lacks meaning to the farming community. In the literature written for the farming community the concentration of nitrate in water is expressed in mg/l. Therefore, to make the results more meaningful, the equation below was used to convert the kg value to mg/l :

$$\frac{\text{Total N load kg}}{\text{Annual runoff volume}} = \text{mg/l}$$

Long term records (1971-2000) from SEPA provided mean daily flow data, signifying an annual runoff volume of 316.19m$^{3\text{-s}}$. This value and the total N load of 285540kg were used in the equation, resulting in an annual N loss of 902.33mg/l. This figure was then divided by 182 (the number of days in the winter period when leaching potential is at its peak), resulting in a winter average daily loss of 4.06 mg/l. However, this value is an average for the whole catchment. It does not take into account the extent of loss in each of the sub-catchments. Table 6.7 below illustrates the results aggregated to each of the sub-catchments contributing to the monitoring station sites[46]. In the monitored sub-catchments the average daily loss ranges from 0.05 to 0.45mg/l. The highest N losses (>0.40 mg/l per day) occur in areas contributing to gauging stations LR007, LR008 and LR010. In each of these sub-catchments arable land use is more than 80% so this can be seen to be one of the contributing factors to such high losses. The lowest N loss occurs in the areas contributing to KR001 and LR011, both these areas have less than 50% arable land.

This method of spreadsheet calculation takes the export coefficient approach forward in that nutrient losses can be applied to specific land cover at the field scale, expressed in mg/l. This technique does however, have one major drawback. The

[46] The sub-catchment for LR-009 is shown artificially large as it comprises a large section of the catchment that was not included in the monitoring process, but did not appear to contribute to other monitoring sites. Like wise for the Eccles sub-catchment, their N loss data has been included in the table for completeness. In addition, 0.3% of the fields plots within the whole catchment could not be assigned to a sub-catchment due to their very small size, however, their contribution only accounts for 0.09% of total N loss.

calculation does not take into account periods of wet and dry weather and in particular heavy rainfall which influence leaching and it therefore cannot predict the precise periods when water quality will exceed the EU limit. However, an approximation of wet periods can be determined from long-term climate averages[47] and therefore the accumulated loading on each field between wet events can be calculated. Data from the UK Meteorological Office indicates that within the catchment, on average, there are 118 days of rain per year with 63.2 rainy days between October and March. On average during the winter, it rains once every 2.9 days. Using this figure to scale up daily average loss, the increased amount of potential nutrient loss relative to rainfall events can be indicated.

Table 6.7 Sub-catchment N losses

CATCH_ID	% Arable land in sub-catch	HECTARES	INPUT_PREC (kg/yr)	TOTAL_FERT (kg/yr)	N_LOSS (kg/yr)	N_mg/l (yr)	N_mg/l (daily average)
Eccles	73.2	814.12	2564.47	150229.90	22533.02	71.17	0.23
kr-001	59.1	1005.82	3168.39	179698.28	22219.61	70.26	0.21
kr-002	71.6	328.30	1034.13	59346.00	8795.21	27.78	0.10
kr-003	46.3	226.69	714.06	41608.72	4507.09	14.21	0.05
kr-004	80.3	449.43	1415.67	82018.60	10690.71	33.81	0.14
kr-006	76.7	710.76	2238.87	139981.12	18692.88	59.09	0.23
kr-007	79.9	468.86	1476.94	88195.58	12511.62	39.48	0.20
kr-008	70.3	399.10	1257.13	71745.46	9146.36	28.91	0.12
lr-003/4	85.8	621.72	1958.41	118231.72	18602.13	58.80	0.27
lr-005	84.0	611.05	1924.80	118735.60	15975.03	50.46	0.22
lr-007	85.9	921.50	2902.72	175559.88	25840.44	81.69	0.41
lr-008	84.0	987.93	3111.96	181818.38	27165.63	85.87	0.45
lr-009	79.1	2130.61	6711.49	383828.64	54215.67	171.40	0.92
lr-010	81.1	1036.84	3266.07	189403.78	29314.44	92.65	0.45
lr-011	29.0	464.06	1461.75	24729.18	5037.70	15.93	0.06
no-id		37.07	116.74	2313.36	292.84	0.82	0.00
Totals		**11213.86**	**35323.60**	**2007444.20**	**285540.38**	**902.33**	**4.06**

Further factors of potential risk can be attributed to each field plot by establishing which plots lie within 50m of the watercourses and therefore pose the greatest threat to water quality. By combining all these factors, the spatial distribution of N loss can

[47] http://www.meto.gov.uk/climate/uk/averages/19712000/index.html

be presented in ArcGIS as risk maps which can be used by stakeholders as part of a suite of land use decision making tools.

In section 6.3.3 the risk maps derived from this data are presented and discussed, then used to model the impacts of range of land use change scenarios.

6.3.3 The nutrient export risk maps for the Leet Water catchment

One of the aims of this research was to provide a user-friendly means of communicating the level of nutrient loss risk to a range of stakeholders including the farming community. One method to achieve this is to produce a simplified, visual interpretation of risk at the field scale based on the loss of nutrients using the mapping software ArcGIS. This is the scale at which the farming community operates. Interviews indicated that the farmers have limited economic resources, so a decision support tool which helps identify particular fields that pose the greatest risk of nutrient loss and therefore threat to water quality would be of great benefit to their situation.

In producing the risk maps, assigning class intervals to the range of values of predicted nitrogen loss needed some consideration. Figure 6.4 below illustrates the predicted annual nutrient loss in kg/yr at the field scale, using the default classification of ArcGIS, the natural breaks method. This method of classification identifies individual fields that have particularly high predicted nutrient losses, but it does not clarify the level of risk to the environment. The classification looks at the spread of values in the data set and assigns class intervals on where that value falls in relation to others in the data set, and how clustering of values occurs. The natural breaks method therefore illustrates the spatial arrangement of the extent of a relative degree of risk of loss from the fields ranked within each range of values.

At present this is the 'best' visual interpretation of risk in terms of identifying individual fields that would contribute to water quality exceeding the 11.3mg/l limit. To achieve a more detailed visualisation would involve a much more rigorous data collection methodology. For example, collecting chemical data on a daily basis to understand the precise annual pattern and quantity of nutrient loss would go some way to achieve this. However, in practical terms the way in which water samples are collected and monitored in the catchment limits the extent to which water quality can be described. Collecting and analysing water samples from a large number of sites in a catchment is costly in financial terms and is labour intensive. These are the two main factors that prevent daily measurements from being collected.

Figure 6.4 Predicted N loss, kg/yr classified by natural breaks

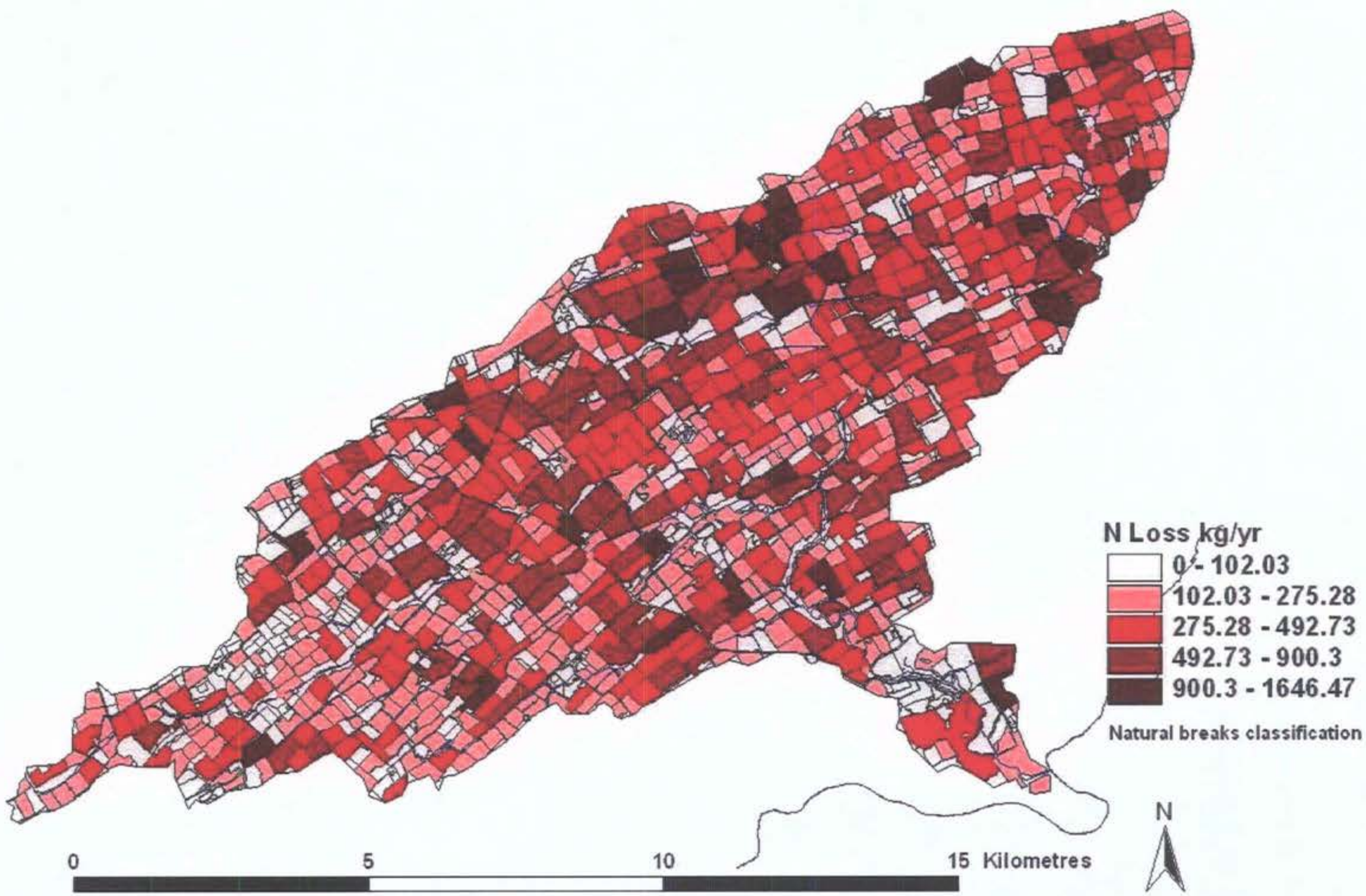
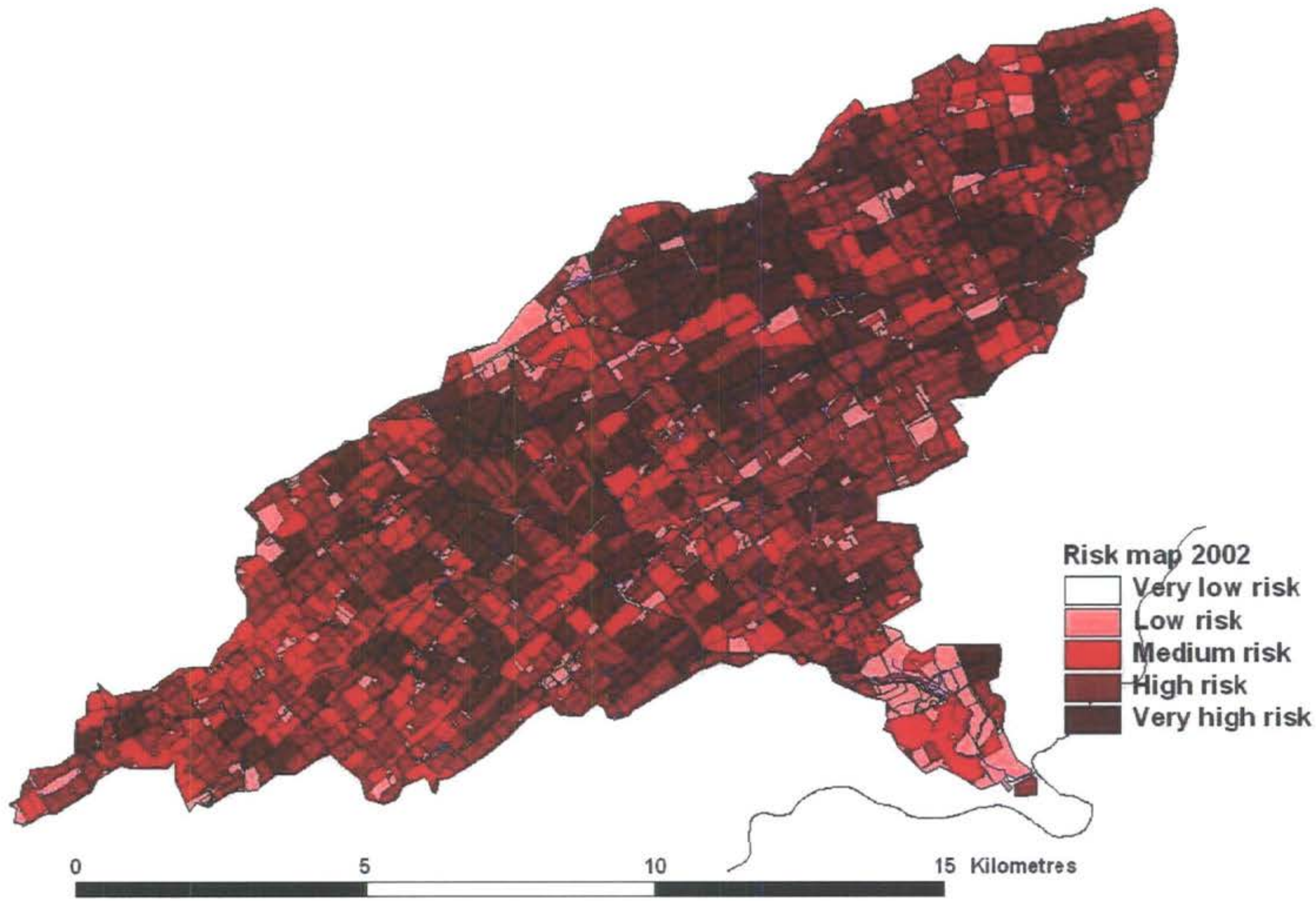


Figure 6.5 Risk assessment map of 2002 land use



All water quality monitoring by SEPA is undertaken by spot measurements at a variety of sites, although due to staffing and economic constraints there is not a predetermined time step between each data set, and the data collection cannot be fully automated (even samples collected by an automated sampler have to manually collected and taken to a laboratory). Furthermore, water samples must either be analysed within 12 hours of collection or be stored correctly to prevent deterioration of the sample. These factors prevent a reliable and precise history of nutrient loss being be gathered for multiple sites within the whole of a catchment.

Risk maps have therefore to be assigned a relative risk using weighted values for a range of criteria. Modelling so far has identified land use and quantified nutrient inputs at the field scale, and the export coefficient identifies those land uses which have greatest potential for loss; when these are combined with a weighting for proximity to a water-course, a combined risk score can be calculated. Weighting values from 1 – 5 are given to the parameters shown in table 6.8 below. For land use, nutrient input and export the full range of weighted values are available for each field. However, for distance from watercourse, the weight range is restricted to reflect the significant contribution of field drains to potential nutrient loss.

Table 6.8 Weighted values for parameters in risk assessment

Land use	Nutrient input Kg/ha/yr	Daily nutrient export N-mg/l	Distance from water course (m)	Weighted value for each variable
Woodland	0	0 - 0.9		**1**
Fallow/ set-aside	1 - 99	1 - 1.9	> 50	**2**
Grazing	100 - 199	2 - 2.9		**3**
Spring cereals	200 - 249	3 - 3.9	11 – 50	**4**
Winter cereals	> 250	> 4	0 - 10	**5**

This enables a total risk assessment score of up to a maximum of 20 points to be assigned to each field plot. Risk can now be classified into five categories based on the following intervals:

Very low risk	1 – 4 points;
Low risk	5 – 8 points;
Medium risk	9 – 12 points;
High risk	13 – 16 points and
Very high risk	17 – 20 points.

Using this method of classification enables a much more realistic assessment of the level of risk each field plot contributes to water quality in the catchment. The results are illustrated in figure 6.5 as a risk assessment map for the whole catchment. These results, summarised in table 6.9 below, show there are no fields in the very low risk category. This is because the proximity to water course weighting forces a minimum possible score of 5 points.

Table 6.9 Summary results of risk assessment of 2002 land use

	Number of field plots in category	Approximate area (ha)	Approximate N loss (mg/l)
Very low risk	0	0	0
Low risk	922	3120	184
Medium risk	414	2219	101
High risk	569	3717	363
Very high risk	191	3256	345

The map produced above can form the basis for comparing the impacts of land use change scenarios. In the next section the current risk associated with field plots with current land use will be compared to that predicted from a range of change scenarios.

6.3.4 Modelling land use change scenarios

Although it has not been possible to predict a precise moment when nutrient loss will exceed the EU limit, the export coefficient model can be applied to predict the impact of changing land use on nutrient losses at the field scale. This modelling will be useful to the farming community as it can provide information to be used in their decision making processes. Currently the catchment includes 74% arable land use which is responsible for 87% of total fertiliser input and 92% of the total predicted nutrient loss. The scenarios below involve changing the way in which arable farming is practised.

The results from a range of modelled scenarios are presented and discussed in terms of how they will impact on arable farming. These scenarios include:

- Applying a 5m grass buffer to all water courses;
- Applying a 10m grass buffer to all water courses;
- Applying a 50m grass buffer to all water courses;
- Reducing existing fertiliser use by 10%;
- Reducing existing fertiliser use by 20%;
- Converting existing agricultural land within the catchment to permanent pasture;
- Converting all agricultural land within the catchment to woodland.

The predicted impacts of the scenario modelling are shown in table 6.10 below. The first land use change scenario involves the installation of fixed width grassland buffers at 5m or 10m, to all water courses in the catchment. These buffers would remove approximately 150 - 320ha of land from production of which approximately 90 – 190ha are currently used for arable production. As part of the management of these buffers, it is assumed that fencing is installed to prevent livestock accessing the stream bed; application of chemicals including fertilisers ceases; and most importantly all field drains discharging to streams are blocked to prevent nutrient losses by-passing the buffer. In the short-term, vegetation would return to rough grassland, although further management of the buffer could include planting native species woodland which would increase nitrate removal in these zones. In these two scenarios nitrogen input is limited to that from atmospheric deposition (3.15 kg/ha/yr) therefore the total N loss is recalculated using the export coefficient for land in set-aside/woodland. Installing fixed width buffers results in N losses being reduced by 0.16 - 0.25% for the whole catchment. In terms of benefits for the farming community fertiliser usage is reduced by 1.17 to 2.47% of the existing use and this would reduce their economic input on the farm. However, this would have to be balanced by the loss in income from grain sales on these buffers.

The buffer scenario is further developed by changing the buffer to 50m. In an intensive arable regime, the land within 50m of the water course can make a significant contribution to nutrient loss. Figure 6.6 below illustrates a section of land use modelled in this scenario. Figure 6.6a shows a section of arable land that exceeded the NO_3-N in November 2002. Under current farming practices, there are a significant number of arable fields adjacent to the water course without any buffers. Therefore the majority of fields are classified as high or very high risk (figure 6.6b). However, with the implementation of a 50m buffer, risk is reduced to low (figure 6.6c). When this model is applied to the whole of the catchment there is a net reduction of total N losses of 1.86%. However, implementing such large buffers may not be acceptable to farmers with smaller farming units as this will remove a greater proportion of their land from economic production.

The second scenario investigated reducing fertiliser use by 10% and then 20% on the existing land use regime. The results found that nutrient losses for the whole of the catchment were 8.8% and 17.5% respectively. In terms of the risk assessment for each field, table 6.11 and figures 6.7a and 6.7b below show this small reduction in fertiliser use can have a significant impact on each field. Under the current farming practice of using the maximum recommended fertiliser rates, 191 fields are classified as very high risk, but this number is reduced to 16 with a 10% reduction in fertiliser use and to 13 fields with a 20% reduction in fertiliser. This also has a knock on effect on fields classified as high or medium risk.

Table 6.10 Results of land use scenario modelling (catchment scale)

Land use scenario	Land removed from production (Ha)	Arable land removed (Ha)	Existing land use contributes fertiliser application		Existing land use contributes annual N loss of		Scenario land use contributes N losses		Net N loss reduction from scenario (%)
			Kg/yr	%	(kg/yr)	(mg/l)	(kg/yr)	(mg/l)	
5m buffer	152.7	90.6	23454.8	1.17	3257.1	10.3	480.6	1.48	0.16
10m buffer	317.3	192.7	49576.8	2.47	6896.9	21.3	9985.9	2.28	0.25
50m buffer	1685.9	1112.3	283289.9	14.11	39158.1	123.6	5310.4	16.24	1.86
10% reduction of fertiliser	0	0	$\sim 2 \times 10^6$	100	285540	902.3	260518.6	823.22	8.8
20% reduction of fertiliser	0	0	$\sim 2 \times 10^6$	100	285540	902.3	235496.9	744.15	17.5
Convert all arable land to permanent pasture	0	8635.9	$\sim 2 \times 10^6$	100	285540	902.3	126567.7	400.4	55.6
Convert all agricultural land to wood	10160.9	8635.9	$\sim 2 \times 10^6$	100	285540	902.3	35323.6	110.9	87.7

Under 2002 land use, fertiliser input was 2,007,444 kg resulting in a total loss of nitrogen to the catchment of 285,540 kg (14.22%)

Figure 6.6a Existing land use with November 2002 NO_3-N data

Figure 6.6b Extent of risk associated with existing land use (within 50m buffer zone)

Figure 6.6c Reduced risk associated with changing land use (within 50m buffer zone)

Table 6.11 Impact of fertiliser reduction to the extent of risk (number of field plots)

	Very low risk	Low risk	Medium risk	High risk	Very high risk
Land use 2002	0	922	414	569	191
10% reduction in fertiliser use	0	922	642	516	16
20% reduction in fertiliser use	0	922	646	515	13

However, farmers believe this scenario would affect the grain outputs from arable production and the number of livestock units per hectare and therefore farm income. On the other hand, farm expenditure on chemical fertilisers and grain seed would be less. For example, at 2002 figures, fertiliser costs were £79 - £105 ha depending on the chemical mix required for the range of crops grown.

The third type of scenario examined the impact of a radical change in land use. Table 6.8 shows that if all arable land use was changed to permanent pasture (i.e. only livestock farming is practiced) nutrient losses are predicted to be 55% less than they are under the current intensive arable regime. However, a 'ranching' style farming system is not popular. This is because cereal production is seen to be more profitable than livestock farming. But more importantly to the farming community, the recent outbreak of foot and mouth disease and previous impacts of BSE have shown how vulnerable livestock can be to contagious or infectious diseases and farmers would be very reluctant to practice such a specialism.

Figure 6.7a Risk assessment based on reducing fertiliser inputs by 10%

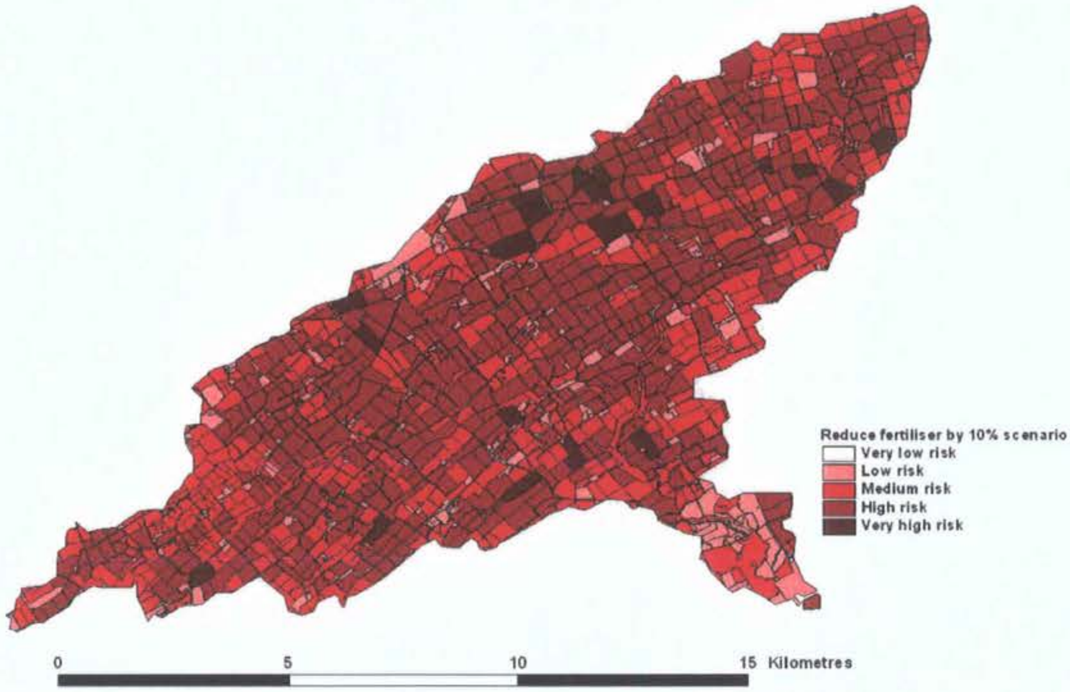
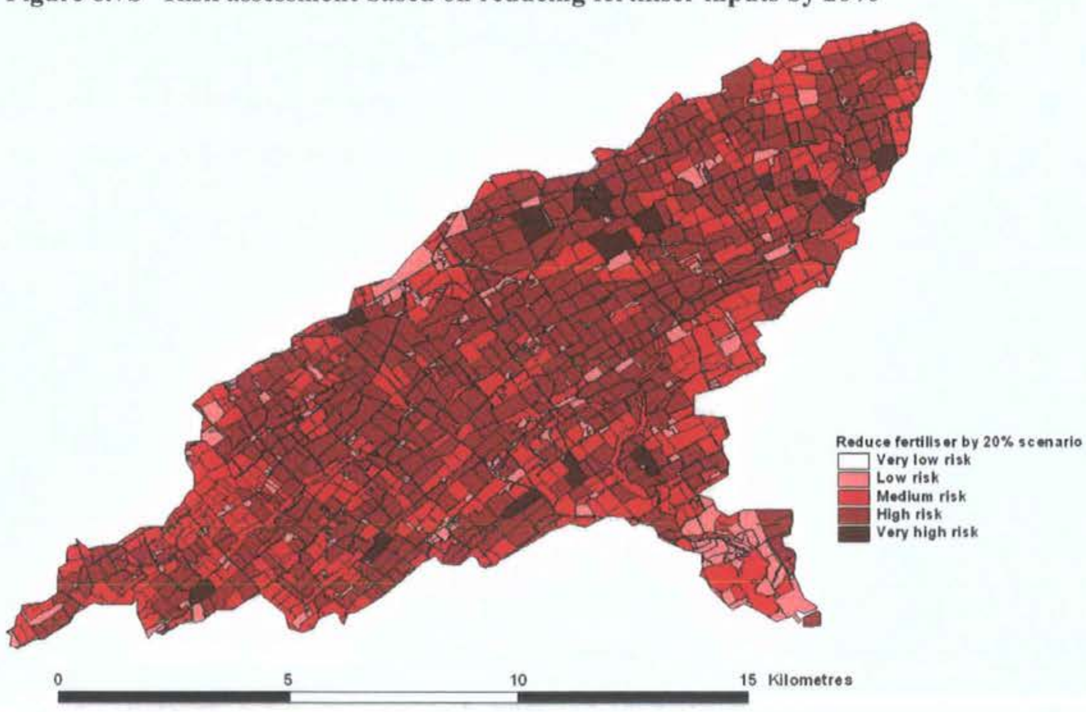


Figure 6.7b Risk assessment based on reducing fertiliser inputs by 20%



The final scenario was the most radical model, requiring all agricultural land (including pasture land) to be taken out of production and converted to woodland. Although this would reduce the current annual nutrient loss from approximately 902mg/l to 111mg/l, the economic, social and environmental impacts are extreme. Assuming plantation woodland takes over, this takes upward of 30 years to mature before felling takes place and an economic return made, so this would not be economically viable for the current farming community. In terms of social change, the range of employment activities in the local area would alter as the specialised skills of forestry workers and the number of workers required change. In environmental terms, although nitrate losses would reduce, there would be increased acidification of water courses, leading to a decline of aquatic bio-diversity. Terrestrial bio-diversity would also change as existing wildlife habitats were destroyed.

6.3.5 Summary of the export coefficient approach

As a decision support tool, the export-coefficient modelling approach has many advantages. These include:

- Its simplicity in calculating a nutrient loss;
- It has relatively few data requirements;
- Its operation uses a spreadsheet (database) system;
- It can be coupled with GIS mapping, providing a visual interpretation;
- It provides a robust and relatively inexpensive means of evaluating the impact of land use and management on water quality.

However there are limitations to this approach, and in particular in this application it was found that:

- Generalisations and assumptions on some model parameters had to be made on information in literature sources;
- Export coefficients cannot be verified without the use of expensive field experimental work;

- The model cannot predict in real time mainly due to variations in transport mechanisms such as hydrological pathways over the annual cycle;
- Assumptions had to be made when converting values from annual to daily rates;
- Assumptions had to be made on rainfall events;
- A lack of daily chemical loss data prevented full calibration of the model.

However, the export coefficient approach enabled a risk assessment to be applied to each field plot in the catchment, and modelling land use change in a range of scenarios has shown that significant changes can be made to the risk associated with each field. This modelling approach can be enhanced. With further research and the development of programme scripting such as VBA, the incorporation of a user-friendly interface could be included. This would enable land cover type to be changed on a field by field basis interactively and/or fertiliser inputs changed. The built in export coefficient equations would then return a new set of scenario maps to demonstrate the change in predicted outcome of nutrient loss. In addition, if these limitations can be overcome, this type of simple, interactive, decision support modelling should be available on a web based interface, freely available to local stakeholders. In terms of data availability for precision land use mapping and fertiliser practices, farmers already produce fully annotated land cover maps and livestock levels as part of the annual return to SEERAD in order to claim their single farm payments. Similar data form part of the annual agricultural census. Detailed data on fertiliser practice are returned to Quality Assurance Schemes, or gathered for official statistical purposes such as the British Survey of Fertiliser Practice. The data are there, they are just not freely available to the research community. If SEERAD (DEFRA in England & Wales) is serious about wanting to support the farming community in its attempts to comply fully with the regulations defined in water quality legislation such as the NVZ of WFD, there must be a will on the part of Government agencies to do so.

6.4 The INCA water quality model

6.4.1 Introduction to INCA

The Integrated Nitrogen Catchment model (INCA), developed by Aquatic Environments Research Centre (AERC, Reading), is semi-distributed, integrating vertical and horizontal catchment and river processes. There are five components to the model, fully described in (Whitehead *et al.*, 1998a; Whitehead *et al.*, 1998b); briefly these are:

- Sub-catchment boundaries and areas of defined land use types, calculated in a GIS using a Digital Terrain Model;
- An N input model that calculates total N inputs from all sources, including dry deposition and application of fertiliser;
- A hydrological component that simulates N fluxes, flow of effective rainfall in the reactive and groundwater zones, and within the river;
- An N process model to simulate N transformations in soil and groundwater;
- A river N process model to simulate dilution and in-river transformations and losses.

Since the first development of INCA in 1995, the model structure and equations have undergone modifications to make it more applicable to a variety of catchments throughout Europe. Recently INCA has been used in ten countries and seven UK research projects (Wade *et al.*, 2002) including the River Tweed (Jarvie *et al.*, 2002). The INCA-Tweed project included data from the Coldstream gauge and land cover of the Leet Water sub-catchment. This literature was particularly useful for early stages of data compilation and modelling, when values of data such as atmospheric deposition and base flow index were not known, thus enabling the baseline data compilation to model the Leet Water catchment in more detail.

6.4.2 Data sets

One of the main advantages of INCA is that data input is kept to a minimum and it uses readily available and relatively inexpensive data sets to drive the five components of the model.

Hydrological and meteorological data: These data are required to drive the water transfers and N fluxes and N transformations through the catchment. This is derived from the UK Meteorological Office Rainfall and Evaporation Calculation System (MORECS) for daily air temperature, hydrologically effective rainfall (HER), soil moisture deficit (SMD) and actual precipitation. Actual precipitation is used to determine the amount and timing of wet and dry deposition inputs. In INCA more than one hydrological data file can be loaded at a time if spatial variation in climate over the catchment is required. As the Lambden Burn and lower Leet comprise a relatively small catchment, only one data file is required.

Reach structure: Reach length is calculated from digital data sets. These are readily available (and free to research institutions) from the Ordnance Survey in the most basic form of OS land-line data. More sophisticated digitised data can be obtained at cost from OS Master-Map or the Centre for Ecology and Hydrology. Velocity/flow (discharge) data can be gathered from automated gauges or routinely measured at specific sites within each sub-catchment. SEPA has two automated gauges within the Leet catchment at Coldstream and Charterpath Bridge, which gather daily data on a long-term basis, and discharge data for the other sub-catchments were gathered at monitoring stations at monthly intervals using an electro-magnetic current meter. Whitehead *et al.* (2002) state that in the absence of daily data, monthly averages can be extrapolated.

Sub-catchment data: In the INCA-Tweed model, area and land use proportions are classified into six broad land cover types (forest, short vegetation un-grazed, unimproved permanent pasture, improved grassland, arable and urban) described at the scale of 1km grid squares. These data can be obtained from the Land Cover of Scotland 1988 (LCS88) digitised data set from the Macaulay Land Use Institute.

Base flow index[48] values are obtained from the literature, such as the Institute of Hydrology HOST classification (Hydrology of Soil Types) (Boorman *et al.*, 1995). In INCA the baseflow index is used to partition water moving through the soil water and ground water reservoirs. The Coldstream base-flow index is quoted as 0.52 in (Jarvie *et al.*, 2002), and a figure of 0.342 for the Leet catchment as a whole is quoted in the Institute of Hydrology report 126 (personal communication John De Groote, Macaulay Institute, Aberdeen).

Table 6.12 below describes the data and sources used in modelling water quality in this study.

Table 6.12 Summary of data used in INCA modelling of the Lambden Burn

Data	***Description***	***Source of data***
Streamwater nitrate and ammonium concentrations	Spot samples from 10 sites along Lambden Burn and Leet Water. Variable sampling 1994 – 2002	SEPA
Streamwater nitrate and ammonium concentrations	Spot samples from 10 sites along Lambden Burn. Variable sampling 2002-2004	Widdison; Research data collection
River flows	Mean daily flows for two gauging stations along Lambden Burn and Leet Water 1994 – 2002	SEPA
River flows	Spot flows from 10 sites along Lambden Burn and Leet Water 2002 – 2004	Widdison; Research data collection
MORECS Rainfall, temperature and soil moisture deficit	Derived monthly time series 1996 - 2004	Meteorological Office
Base Flow Index	Derived for each flow gauging station and extrapolated to ungauged river reaches	Institute of Hydrology
Fertiliser application rates		The Farm Management Handbook 2003/04 (SAC)

[48] Base flow index (BFI) is a measure of the proportion of river runoff which is derived from stored sources i.e. BFI determines the transfer of water from the soil reactive zone to the groundwater and reflects the geology of the area – high values indicate more permeable soils, lower values indicate clay lithologies

6.4.3 INCA model setup

To model nitrate (as NO_3-N) in the Lambden Burn and lower Leet, the sub-catchment was divided into ten reaches of less than six km in length, the boundaries of which coincided with the gauging stations described previously. This enabled comparison of observed flow and chemical concentration to model simulations. Three comma delimited data files are required to run INCA. These provide catchment descriptions (*.par), hydrological daily time series (*.dat) and a file of observed flow and water quality data (*.obs). There is no header information in any of these files so it is essential to understand the data content of each file.

The parameter file (*.par) is the most complex file in the series, containing sixty-two rows of data that provides information on title, land use groups, initial conditions of the land phase, time steps, land phase parameters, in-stream initial conditions, number of reaches, reach descriptors and inputs, and sub-catchment descriptors and inputs. Header information and descriptions are not included in the file so for clarity the row numbers and description of data are described in Appendix 6.2.

The Input hydrological data file (*.dat) contains information in daily time steps (in rows), and in columns data (from left to right) on soil moisture deficit (SMD); hydrologically effective rainfall (HER), air temperature, and actual precipitation. Data for this file is readily available from MORECS.

The observations file (*.obs) comprises two columns of data, separated into reach specific data. Column one is the calendar date of observations, and column two the values for observed flow, NO_3 and NH_4. Examples of the data entry are shown in figure 6.8 below.

Figure 6.8 Example of the *.dat and *.obs file for INCA

lambden-hydro-data-94-00.dat

0	0.69	-1.1	8.7
0	0.02	1.1	0.2
0	1.33	1.5	8.5
0	0.02	-0.9	0.1
0	10.26	-0.7	26.1
0	2.21	1.8	5.1
0	0.04	1.9	0.1
0	0.26	-0.1	0.6
0	1.72	2.4	3.8
0	0.04	2.7	0.1
0	2.11	1.8	4.4
0	4.78	4.3	8.7
0	8.64	3.9	13.1
0	0.72	4.1	1.1
0.06	0.00	0.6	0
0	0.45	0	0.7
0	2.05	1.1	3.1
0	1.34	2.2	2
0.06	0.07	3.4	0.1
0.05	0.06	5.1	0.1
0.5	0.00	8.5	0
0	3.03	5	4.6
0.41	0.13	3.1	0.2
0	2.76	5.5	4.1
0	4.29	4.1	6
0	5.94	4.2	7.7
0.27	0.92	3.4	1.2
0.71	0.23	1.7	0.3
0	1.92	3.9	2.5
0.58	0.23	3.9	0.3
0	5.02	4.7	6.3
0	9.02	4.9	10.3

Example of the *.dat file

lambden-obs-94-2000.obs

```
**************************** Reach 1 *************************
---------------------------- NITRATE --------------------------
07/01/1998      13.1
25/03/1998      9.7
21/04/1998      10.5
10/06/1998      7.7
05/08/1998      6.8
14/10/1998      8.8
16/12/1998      8.2
**************************** Reach 2 *************************
---------------------------- NITRATE --------------------------
07/01/1998      14.7
25/03/1998      10
21/04/1998      11.6
10/06/1998      10.1
05/08/1998      7.6
14/10/1998      9
16/12/1998      10.7
**************************** Reach 3 *************************
---------------------------- NITRATE --------------------------
07/01/1998      14.7
25/03/1998      10.3
21/04/1998      11.6
10/06/1998      10.1
05/08/1998      7.5
14/10/1998      9.2
16/12/1998      9.4
```

Example of the *.obs file

Simulated nitrogen concentrations in the land and in-stream components depend on water volume, so the hydrological component of INCA was calibrated to initial observed conditions from user-defined estimates of river flow, NO_3 and NH_4 concentrations in the furthest upstream reach. This can either be edited manually in lines 39-41 of the parameters file, or on-screen using the menu command **Edit | Parameters | River** then entering the initial values for reach one in the dialog box:

Flow 0.780;

NO_3 8.8;

NH_4 0.07.

To complete the initial set-up of the model, some observed data are required. This includes, fertiliser inputs, deposition inputs, crop growth periods and if applicable, effluent / abstraction data. Long-term data sets may be obtained from government survey statistics or environment agencies such as SEPA. Shorter time series data may be gathered as part of fieldwork within a research project. Although daily time series will provide the most accurate calibration, usually this is not available for the whole of a catchment so data at less frequent intervals e.g. monthly can be used to give a more general view of conditions in the catchment. In this study nitrogen deposition inputs have been taken from Jarvie (2002) to be 3kg ha^{-1} yr^{-1}. Crop growth periods including start and harvest dates timings were obtained from farm management handbooks (Chadwick, 2003) or farm survey. Flow data, nitrate-N and ammonium-N were provided from long-term monitoring by SEPA as spot measurements, usually five or six readings per annum.

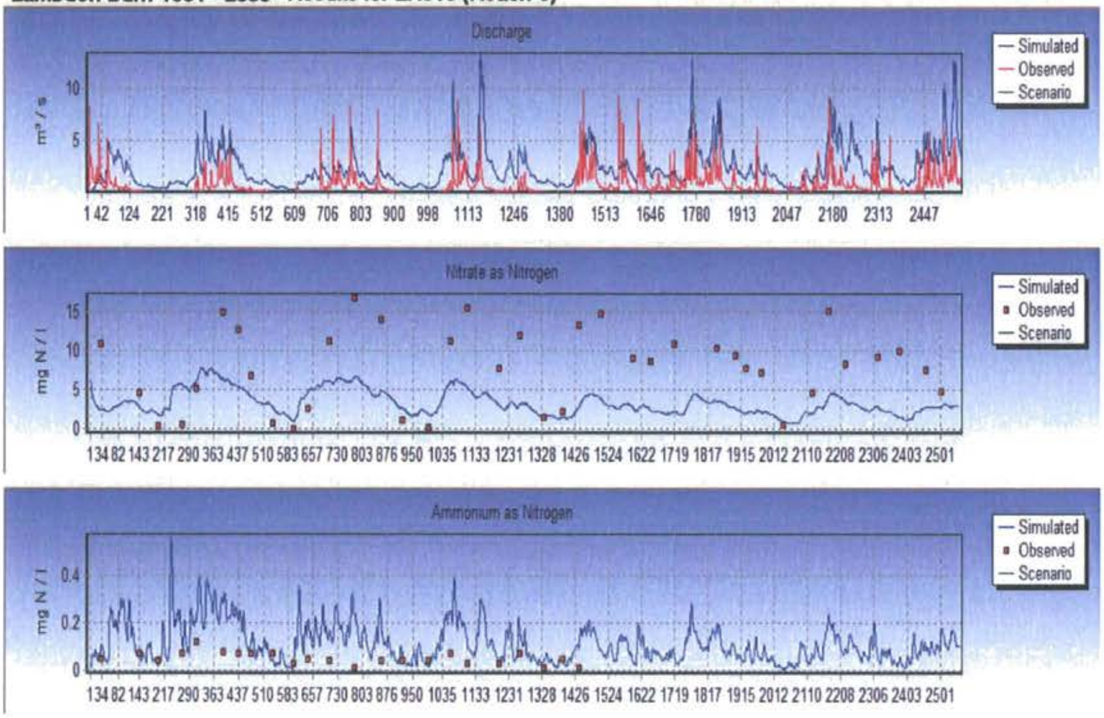
6.4.4 Calibrating the model

Figure 6.9 below illustrates the results of the first run of the model using the parameters derived from literature sources quoted above for the period January 1st 1994 to December 31st 2000 (2557 daily time-steps). In this example, reaches 9 and 10 (gauging sites LR010 and LR011) are described as they contain data required for all parameters. The simulated (blue lines) and observed (red squares) values in the model run reflect the seasonal patterns of winter highs and summer lows for discharge, nitrate and ammonium leaching. However, throughout the period, in reach 9 for discharge and ammonium, the model simulation overestimates the observed data. At reach 10, discharge and ammonium are more closely matched. For nitrate at both reaches, the summer lows are relatively well matched, but winter leaching is underestimated.

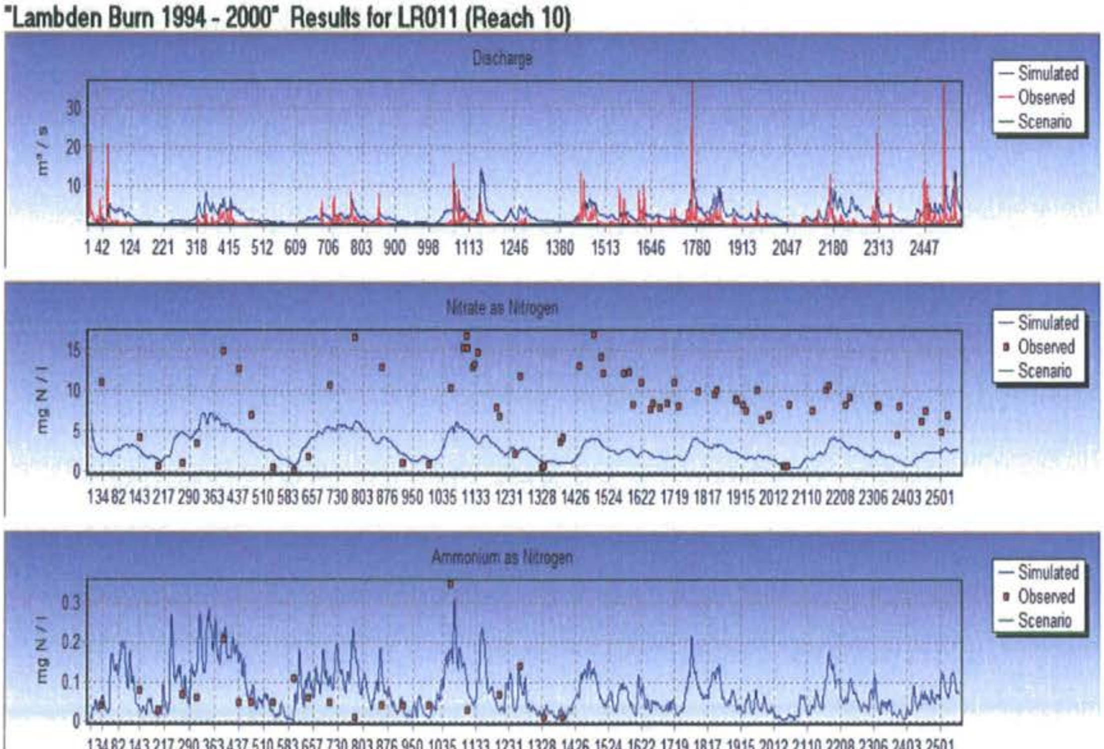
This result confirms the importance of calibrating the model parameters controlling nitrogen transformations. Calibration is achieved by iteratively adjusting the constants and initial value parameters until the simulated model matches the observations to the best acceptable level (Butterfield *et al.*, 2004).

Figure 6.9 INCA model run 01 – simulated and observation results [49]

"Lambden Burn 1994 - 2000" Results for LR010 (Reach 9)



"Lambden Burn 1994 - 2000" Results for LR011 (Reach 10)



[49] The INCA screen capture graphs legend includes a 'scenario result' even though this part of the model has not been run.

The INCA user guide suggests a series of steps should be followed for calibrating the model:

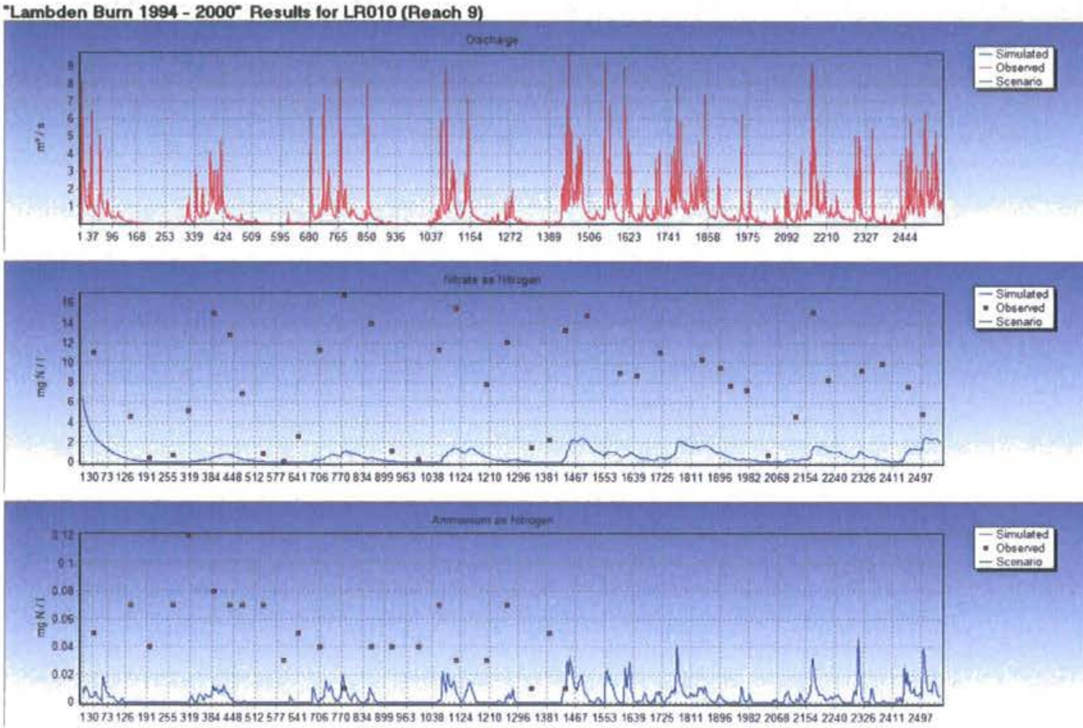
Step 1 – adjust land phase constants;
Step 2 – adjust land phase initial conditions;
Step 3 - adjust soil water and groundwater time constants;
Step 4 – adjust HER;
Step 5 – adjust fertiliser application rate and plant growth periods;
Step 6 – adjust land phase process rates;
Step 7 – adjust in-stream process parameters.

Steps one, two, and three were tried with a range of values but none seemed to provide an acceptable fit between simulated and observed values for all three measurements. In particular, after each model run, qualitative assessment of the difference in observed and simulated values for discharge was considered to be too great. The model continued to overestimate discharge for all reaches. Butterfield *et al.* (2004) suggest that if simulated flow is in excess of that observed, then the HER estimate may be too high. Step four, enabled a new estimate of the HER value to be calculated for the *.dat table. This was achieved by using the observed rainfall-runoff ratio for the catchment, then multiplying this by actual precipitation. The disadvantage of this method is that it does not take into account seasonal variation in evapotranspiration. Observation in the catchment over two summer periods confirms that discharge in the Lambden is very low and some reaches dry up, so using a simplified HER may affect the simulated results.

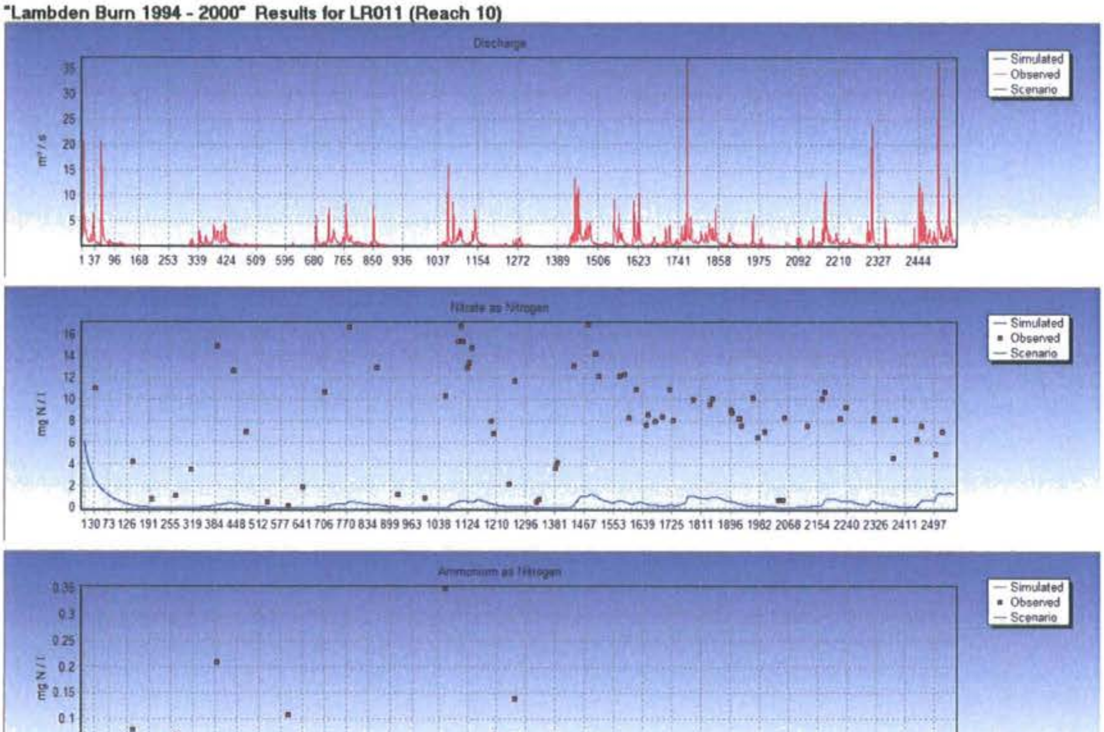
When the calibration was run with the new parameters, values for simulated discharge appeared to be more accurate in the upper reaches of the Lambden, but observed values for discharge mask the very low values simulated at reaches 9 and 10 on the Leet. Furthermore, figures 6.10a and 6.10b below illustrate that the differences between observed and simulated nitrate and ammonium are not adequately matched.

Figure 6.10a INCA calibration run 01 [50]

"Lambden Burn 1994 - 2000" Results for LR010 (Reach 9)



"Lambden Burn 1994 - 2000" Results for LR011 (Reach 10)



[50] The INCA screen capture graphs legend includes a 'scenario result' even though this part of the model has not been run.

Taking these factors into consideration it was decided that amendments to the HER values were not required for the calibration of the INCA-Lambden parameters. A satisfactory fit could not be found even though significant changes to constants and initial values used in the parameters file (*.par) had been made. These are shown in table 6.13 below. It was therefore considered that the Lambden/Leet data was not acceptable, and further progress with modelling land use change scenarios could not continue at this stage without further research into actual conditions in the catchment.

Table 6.13 Calibration changes for parameter file in INCA modelling

	from	to	effect
Change for constants			
V_r max	0.45	0.17	Increase soil water NO_3 concentration
Soil reactive zone	2.3	1.5	Make soil water response faster and more 'peaky'
Groundwater	23	15	Generate a faster groundwater flow response
Change for initial values			
Surface flow	0.001	0.01	Increase soil water flow at beginning of simulation period
Surface Nitrate	3	15	Increase concentration of NO_3 at beginning of simulation period
Subsurface Nitrate	4	10	Increase concentration of NO_3 at beginning of simulation period

This inability to achieve an acceptable calibration could be due to several problems such as:

- A defective program;
- Inappropriate data / unreliable sources;
- Model scale insensitivity;
- User error.

A defective program was discounted as the model based on INCA-Tweed data ran perfectly well. The disc containing data and model programme were copied and re-loaded onto the computer without problems.

Inappropriate data or unreliable source of data was also discounted as data for this project were acquired from the same sources used in INCA-Tweed; i.e. from the UK Meteorological Office, SEPA and the Macaulay Land Use Institute.

Model scale insensitivity was considered. INCA has previously been applied to large river basins such as the Tweed (4600 km^2). Other applications include, the River Tywi in South Wales (1090 km^2), the River Ouse, eastern England (8380 km^2), the River Kennet (1200 km^2), and the Simojoki river basin, Finland (3160 km^2). It is possible that this may contribute to lack of acceptable calibration as at 114 km^2 the Leet sub-catchment may be too small to model nitrogen processes accurately, or include sufficient process realism.

User error was also a strong contender for poor calibration. However, model calibration had been tried on numerous occasions over a period of several weeks. Each time, carefully following the instructions in the user guide and similar calibrated results were experienced on each occasion. Despite this, it is possible that manual calibration by the user is not following the correct protocol and this may be the cause of the problem.

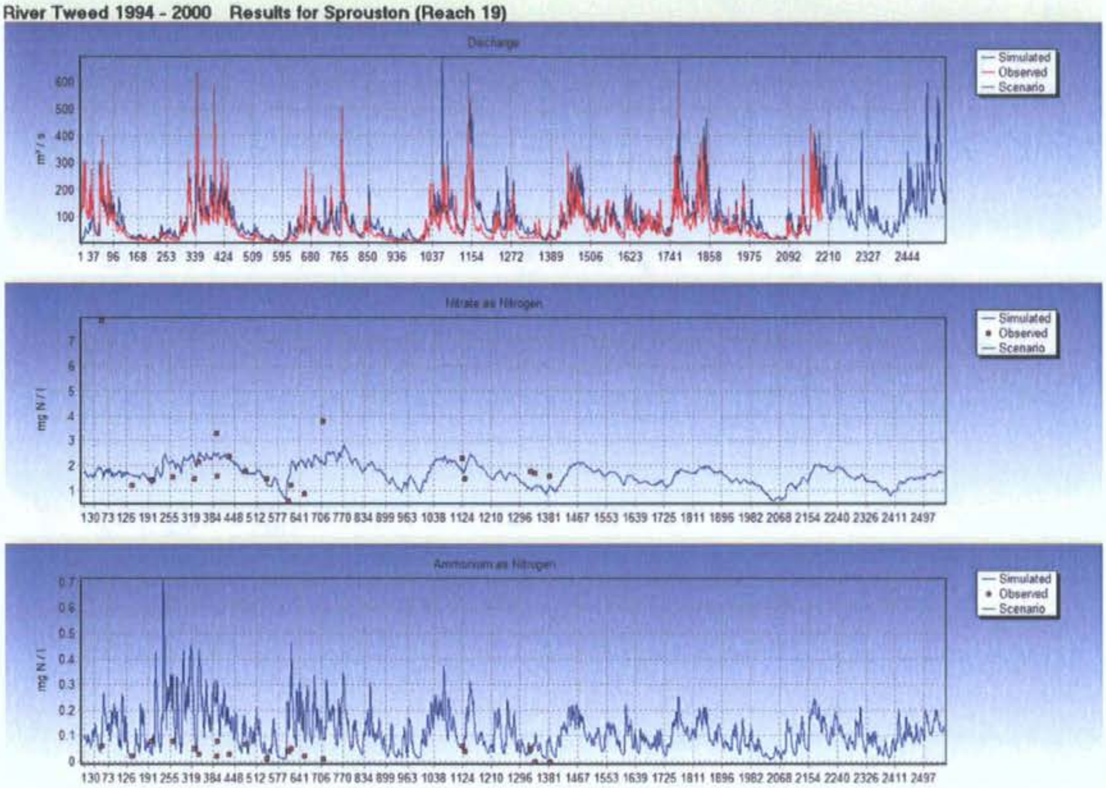
This research was fortunate to have a copy of the data files used in the INCA-Tweed project. Although the data in this version of the model are for the main stem of the Tweed, it was decided to use reach 19 (Sprouston, approximately 13km upstream from Coldstream) and reach 21 (Coldstream) as a comparison for assessing the level of precision in matching observed and simulated values for discharge, nitrate and ammonium.

Figure 6.11 below demonstrates that INCA-Tweed appears to have achieved a good fit between simulated and observed nitrate at both reaches, except where very high concentrations of nitrate occur, such as, at days 54, 393 and 714 at Sprouston, and at days 54 and 1481 at Coldstream. The model simulation overestimates ammonium concentration at both reaches. From this it appears that INCA-Tweed underestimates extreme nitrate concentrations, and this is reflected in the calibrated data for Leet/Lambden. This may be due to the very high concentrations of nitrate and the extent of nitrate leaching that occurs in the study area combined with low flow that reduces the dilution effect that is found in the main stem of the Tweed .

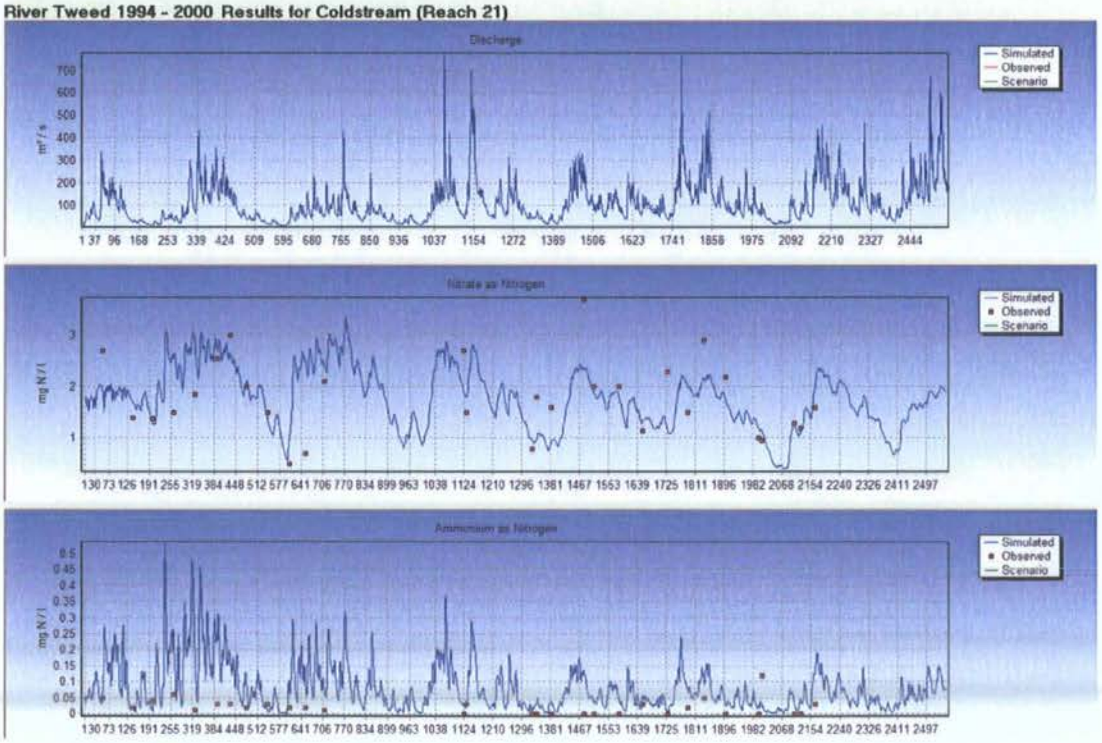
From these figures, there appears to be a very good fit between observed and simulated flow values at Sprouston. Although some discrepancy can clearly be seen for very high flows (those > $300m^3s^{-1}$), the discrepancy for average values is more difficult to assess. For example, between days 478 and 509, there also appears to be a very good fit between observed and simulated values. However, examining the actual values in the model run reveals that observations range from 23 to $15m^3s^{-1}$. Whereas simulated flows range from 47 to $70m^3s^{-1}$, similar patterns occur during other periods of low to average flow, indicating there are significant differences between the observed and simulated flows. One of the key differences between the Tweed data and the Lambden/Leet data is the magnitude of discharge. The average mean daily flow during the model period for the Tweed at the Sprouston gauge was $67.7m^3s^{-1}$. Generally, low discharge, < $10\ m^3s^{-1}$, occurred during the summer months (July – September); and high flows, those that are >$100m^3s^{-1}$ and < $400m^3s^{-1}$ between October and March. Some very high flows of over $400m^3s^{-1}$, were recorded between 1994-2000. However, average flows on the Leet at Coldstream were only $0.087m^3s^{-1}$, with high flows being regarded as those between 1 and $5m^3s^{-1}$. Highest flow on the Leet was recorded on 3rd November 1998 with a discharge of $37.3m^3s^{-1}$, compared to $614m^3s^{-1}$at Sprouston on the same date. Therefore the range of flow data for the Tweed is several orders of magnitude higher than that of the Leet, thus demonstrating that the magnitude of flow in the Tweed masks the extent to which the Tweed overestimates simulated flow. This could indicate that INCA cannot be successfully calibrated in a catchment where water courses are very small, and flow is low. In addition, the fit between observed and simulated values of nitrate in INCA-Tweed are much closer than the fit that could be achieved with the Lambden Burn data. Again this could be that the extreme observed values cannot be calibrated with the current data.

Figure 6.11 INCA-Tweed model run for Sprouston and Coldstream

River Tweed 1994 - 2000 Results for Sprouston (Reach 19)



River Tweed 1994 - 2000 Results for Coldstream (Reach 21)



6.4.5 Criticisms of INCA-Tweed basic parameters – How could INCA be further developed to make it applicable to small catchments?

Land cover: At the 1km grid square, land use can be mis-classified. For example in INCA-Tweed, land cover for the Coldstream reach is only described for two of the six prescribed land use types: 96% arable and 4% improved grassland. By using more detailed data, a more realistic picture of land cover can be built into the model parameters. In land use change scenario modelling this may be of significance, as some of the water courses have rough grazing or forestry as bank side vegetation and this will affect the rate at which pollutants reach the water courses. Although individual farm-by-farm field scale data are collected for the annual agricultural census, these are not available to the research community due to confidentiality issues. In this research, accurate land cover mapping in the study area was obtained from farmers' records (personal interviews) and the use of aerial photographs and multispectral remote sensing data acquired from the NERC ARSF. Using the derived land cover map to classify each sub catchment, it was found that in six of the ten sub-catchments of the Leet Water, all six INCA land cover types were classified, and in the other four sub-catchments either four or five land cover types were found.

Calibrating INCA: It was believed that the appropriate data sets had been obtained to build an accurate parameters file. However, it was not possible to achieve an acceptable fit between the simulated and observed values of nitrate.

Land use change scenario modelling: The 1km land cover grid used in INCA is a very coarse resolution. At this scale, land use change scenarios at the field scale cannot be modelled. In this section of the research it was intended that modelling small changes in land cover could be shown to benefit water quality and interactive modelling could be developed. It has not been possible to do this. Although INCA can indicate the benefits of changing the percentage of land within a sub-catchment, these changes cannot be directly related to the farm scale. Furthermore, it is not possible to predict the effects of a change in land cover at specific locations in the sub-catchment. It is widely accepted that what goes on in the riparian zone is of crucial importance in the transport of nutrients from agricultural land to the water-course. If INCA could be developed to show changing land use, say within 100m of water-courses, this would be great interest to the farming community and management stakeholders. At present using the 1km grid scale or sub-catchment scale, it is difficult to convince individual farmers that their decisions can have a direct influence on water quality. However, if it could be shown that taking land adjacent to water courses out of production (be it arable or grazing), breaking up field drains and so forth had a direct beneficial effect on water quality and improves the environmental bio-diversity by increasing wildlife habitats – this would be a much stronger tool to use in land use management discussions with the farming community.

6.5 Summary results of water quality and land use change scenario modelling

A series of nitrate concentration maps based on collected water samples illustrates the spatial extent of the water quality problem in the Lambden and lower Leet over a period of 20 months. These confirm the seasonal pattern of nitrate leaching, and are useful in illustrating such trends, but do not indicate the source of nutrients.

This research has found that modelling predicted nutrient losses at the field scale using a modified export coefficient approach as a series of risk maps can identify particular land use types that contribute to water quality problems or are potentially vulnerable, such as locations in close proximity to water courses. Land use change scenario modelling has shown that radical change is not always necessary to have an impact on water quality. Small changes to existing farming practice, such as reducing fertiliser use, can have an impact on the risk associated with each field plot. This modelling approach has much potential for development as a user-friendly interactive decision support tool for stakeholders in agricultural catchments.

The literature describing results from studies using the water quality model INCA has shown this to be successful at modelling the overall impacts of land use change at a variety of scales from very large river basins of thousands of km^2 down to the contributing area of an individual reach. INCA would therefore be very useful for river basin managers as part of an overall planning strategy. However, INCA does not indicate what is happening within an individual field or identify those fields that are particularly vulnerable to nutrient loss other than by grouped land use. Concerned stakeholders, wanting to consider the impacts of land use change scenarios, would find this scale difficult to work to. For example, the users may want to know the impacts of reducing arable production by 10% at the farm scale, but this is not possible at the present time with this model.

In the next chapter these results will be discussed in the context of EU policy implications and the availability of funding to implement practical agri-environment schemes. Case studies highlight the extent that the farmers in this catchment think they can modify their day-to-day farm management decisions to comply with regulations.

Chapter Seven:

Can farmers implement land use change to benefit water quality?

7.1 Introduction

In Chapter Six it was shown that a modified export coefficient approach could model predicted nutrient losses at the field scale and identify particular land use types that contribute to water quality problems or are in potentially vulnerable locations. In this chapter those results are discussed in the context of EU policy and the availability of funding to implement practical agri-environment schemes. Case studies highlight the extent to which farmers in this catchment think they can modify their day-to-day farm management decisions to comply with regulations. To achieve this, the following points are addressed:

- Identifying existing agricultural initiatives and those resulting from recent EU policy changes and implementation such as the WFD and CAP reforms. For example, the requirements of Nitrate Vulnerable Zone (NVZ) designations, the Rural Stewardship Scheme (RSS), the introduction of the Single Farm Payment Scheme (SFPS), and Land Management Contracts (LMC).

- Modelling and evaluating the costs and benefits of economic decisions and their environmental effects related to the above including:
    - Decreasing nutrient inputs;
    - Changing crop patterns;
    - Changing livestock levels.

- To what extent can farmers' day-to-day practices and decision making (as influenced by policy instruments) be modified to improve the quality of water in the catchment?

- Can a user-friendly GIS land management tool be designed to be of benefit to farmers and other stakeholder groups?

7.2 Pre 2005 agricultural payments and initiatives

Prior to January 2005, there were a number of direct support schemes and financial incentives available to all sectors of the EU farming community. These not only offered advice and guidance on how to improve day-to-day farm management beyond a basic level of good agricultural practice, but also provided a significant source of income. These schemes were funded from the EU CAP budget from two categories (known as Pillar I and Pillar II[51]) and administered by the Integrated Administration and Control System (IACS[52]). However, under the CAP reform agreement of 2003, Scotland opted for full decoupling (cutting the link between support and production subsidies) introducing a new system of single farm payments which came into force in January 2005 and will be fully implemented by 2007.

This change has caused considerable concern to the farming community as the full economic impacts are still unclear. To set this worry in context section 7.2.1 outlines the main direct support schemes in place prior to decoupling. Section 7.2.2 describes further funding sources available for entry into voluntary and mandatory schemes.

7.2.1 Direct support schemes

Direct support schemes (Pillar I), administered by the IACS provided the main payments from CAP for arable and livestock farmers. Although these payments were subject to modulation[53], the farming community were able to access the

[51] Pillar I payments refer to direct support schemes; Pillar II payments are for 'rural development support, delivering public benefit that cannot be achieved through the market'. Agri-environment schemes are included in this category.

[52] IACS established a system to control and combat fraud in CAP arable and livestock schemes. IACS is an important part of the European Unions CAP Reform measures agreed in 1992. The IACS rules are set out in Council Regulation (EEC) No 3508/92 and Commission Regulation No 2419/2001.

[53] Modulation redirects a proportion of CAP subsidy payments (Pillar I) into agri-environment and rural development schemes (Pillar II) and was first introduced in the UK in 2001 at a low, flat rate of 2.5% increasing gradually over time. The 2003/4 rate of modulation was 3.5%.

modulation fund through agri-environment schemes (Pillar II). The direct support payments included nine categories for arable and livestock farms:

Arable area payments. This scheme (AAPS) was a voluntary scheme, which offered area payments on eligible land to growers of cereals, linseed, oilseeds, protein crops, flax and hemp. Farmers claiming AAPS cropping aid on more than 17.66 hectares in the Less-Favoured Area (LFA), or more than 16.23 hectares in the non-LFA, also had an obligatory set-aside requirement. Farmers claiming on areas less than those specified above did not have to set land aside, but could do so on a voluntary basis. Payments for LFAs were £222.73/ha and non-LFAs £242.39/ha in 2003/4.

Beef special premium: This scheme was introduced in 1993 to give direct support to beef producers. Only male cattle were eligible for a premium, and a beef producer undertook to retain claimed animals on the holding for two months from the day after the Department received the application, unless a later date was specified on the claim form. Payments rates were: steers £92.95; young bulls £130.12. Payment for male castrated cattle could be claimed twice in the animal's life, once between 7-24 months and then aged >24 months. A bull received one payment any time after 7 months.

Suckler cow premium: This scheme was designed to help support the incomes of specialist beef producers. The premium was paid on suckler cows and heifers (over eight months old), forming part of a regular breeding herd used for rearing calves for meat. Milk producers actively involved in milk production, with milk quota less than 180,000kg (174,780 litres) could also claim SCP as small milk producers. £123.93, was paid up to a maximum of 1.8 LU/ha.

Slaughter premium: This scheme was introduced in 2000 to give direct support to cattle producers. Animals eligible for the slaughter premium were bulls, steers, cows and heifers slaughtered from the age of eight months. There was also a separate element of the scheme known as the veal calf slaughter premium scheme (VCSPS) for animals slaughtered at more than one and less than seven months old. For cattle over 8 months payments were £49.57, and for those under 7 months £30.98, subject to a national maximum number of 3,266,212 animals. If this total number was exceeded then payments were reduced accordingly.

The sheep annual premium: This scheme provided for the payment of an annual premium to sheep meat producers. Payment was based on the number of female sheep that, by the last day of a specified 100-day retention period, had either given birth to a lamb or attained the age of 12 months. The payment of £13.01 (with a LFA supplement of £4.34 if appropriate) was in the form of a flat rate premium.

The beef national envelope: This scheme had a fixed budget of 63.8 million Euros, usually paid as a top up to the suckler cow premium, with regional discretion on how to make payments. Since BSE cattle aged >30 months old are prevented from entering the food chain, on slaughter, carcases were destroyed so farmers were compensated at the following rates: breeding cows 0.64 euros/kg live-weight, other cattle 0.83 Euros/kg live-weight. However, this payment was phased out in January 2004.

The sheep national envelope: This scheme had a fixed budget of 20.162 million Euros and was paid as a top up (at 72p/head) to the Sheep Annual Premium, but producers had to belong to a quality assurance scheme to qualify for payment.

The extensification payment scheme: This scheme was based on two sub-schemes, the **simplified** and the **standard scheme**. A producer chose one of the schemes, and could not switch between them during the scheme year. For both schemes there were two stocking density bands: below 1.4 LU/hectare, and below or equal to 1.8 LU/hectare. Payment bands were £24.79 for < 1.8 LU/ha, and £49.57 < 1.4 LU/ha.

The less favoured area support scheme (LAFASS). The principle behind this scheme identified eligible land according to designated grazing categories, followed by adjustments to account for stocking density restrictions, and the influence of cattle on the holding. Payment was made at rates according to location. In 2003/4 these were: Very Fragile (Islands) £44.50 per ha; Fragile £42.50 per ha; and, Standard £36.50 per ha. Claiming for LFASS was part of the process of completing an Area Aid Application (AAA) form although not subject to modulation.

However, all the above schemes apart from LFASS have now been abolished and replaced by the single farm payment. The implications of this are discussed in section 7.5.

7.2.2 Agri-environment and farm improvement schemes

Voluntary schemes that contribute to rural development are funded from CAP Pillar II. The ***Rural stewardship scheme*** (RSS) has been, and will continue to be another important source of funding for farmers. However, this scheme is discretionary and funds are allocated according to a ranking score. To be eligible, the farmer must prepare a full environmental audit of the farm with detailed maps and choose from a range of options described in the documentation. Successful applicants are expected to meet the chosen requirements for a minimum of five years which may be extended for an additional five years. The minimum requirements of the RSS include:

- Managing specific areas of land and undertaking capital works in accordance with the chosen options;

- Following general environmental conditions and standards of good agricultural practice over the whole farm.

Under RSS there are also a range of capital payments mostly relating to improving stock fencing & providing water piping and troughs away from existing water courses, restoring dry stone walls (dykes), and planting native tree species. In addition, annual management payments cover a comprehensive range of 33 options. Some are site-specific, e.g. management of coastal heath, management of archaeological sites, creation and management of wetland, and retention or introduction of native/traditional livestock breeds. Others are management options that can be applied to a variety of farm types, for example, management of water margins, conservation headlands, extended hedgerows, scrub, woodland and so forth. However, entry into the RSS can be very difficult and requires a capital outlay of several hundred pounds for the farm audit before the process of application begins. Because of this, the scheme has been the subject of criticism from both the farming community and advisory organisations.

In addition to the RSS, Scottish farmers could apply for funding under the ***Scottish forestry grants scheme*** (previously the Woodland Grant Scheme), for establishing productive native woodland, in particular for riparian habitats. However, the minimum area must be 0.25ha with a minimum width of 15m. The standard targeted grant is 60% of costs, but up to 90% can be paid if most of the benefit is to the public rather than the landowner. For example, amenity tree planting attracts £1.50 each, plus £1.60 for stake and tree guard; hedge laying/planting £4.00m. Applications are made from one of three categories:

- Stewardship – for woodland management;
- Woodland expansion;
- Replanting or restocking felled woodland.

Successful applications were awarded on a first come, first served basis, so many applicants did not get funding in their year of choice.

The farm improvement grant (FIG): This was a standard grant (usually up to £16,000), principally aimed at young farmers in the 18 – 39 age group. In exceptional circumstances, 40% of capital expenditure to a maximum of £20,000 can be awarded for improvements under one of three categories:

- Waste management: developing efficient management of farm wastes in an environmentally sensitive manner;
- Livestock and crop husbandry: developing facilities designed to reduce costs of production, improve or re-deploy production, increase quality, preserve and improve natural environment, improve hygiene and animal welfare conditions;
- Resource management: encouraging the sustainable use of resources.

A range of other grants aimed at farm enterprise and/or diversification encouraged the development of ideas under the auspices of rural development. For example, those related to education or tourism such as farm visits, farm walks, or cycle routes. Other enterprises may provide a benefit to the local community such as providing new job opportunities.

Clearly there have been a large number of funding opportunities from voluntary schemes, and many farmers successfully applied for such funding. However, there were major criticisms of the funding format. These included:

- Farmers were unaware of all the available options – indeed a 'one stop shop' providing such information did not exist;
- If a farmer found an interesting option, application was complicated. For example, the RSS information book comprises 125 pages to read and understand in order to see if they are eligible for the scheme (a task many farmers' find daunting);
- Limited funding of schemes meant many farmers were unsuccessful, even after several attempts to get into the scheme.

In the following section, case studies of two contrasting farms are described to illustrate how these schemes could be applied.

7.3 Conservation opportunities on a large mixed farm in the Scottish borders

The pilot study for farmers' interviews not only enabled the structure of relevant in-depth questions to be formulated, it also provided detailed information on the type of conservation measures that could be applied to a mixed farm and enabled costs and benefits of land use changes to be evaluated. However, it must be stated that the type of land use changes that are encouraged in existing agri-environment schemes such as the Rural Stewardship Scheme are not specifically directed at improving water quality. The majority of projects within the remit of such schemes aim to improve overall bio-diversity but, if sited in appropriate locations, this will indirectly benefit water quality in adjacent watercourses.

The farm described here, although not within the Leet catchment, is partly within the Lothian and Borders NVZ, so is an appropriate case study as it is subject to the same requirements as farms in the study area. This a family run business comprising 650ha, of which 275ha are permanent and rotational grassland for 140 beef cattle and

1150 breeding ewes. Arable land of 220ha produces wheat, barley and oats. There are large areas of established broadleaved woodland.

In anticipation of changes to the way farm payments would be made from January 2005, applications for grants available under The Rural Stewardship Scheme (RSS) were made. In addition to the perceived environmental benefits, it was reasoned that this would be a way of recouping money clawed back under the 3% modulation imposed by the EU. At the interview this farmer stated that the application process for the RSS scheme was very time consuming and complicated – three months were spent by the farmer's wife and the local FWAG advisor investigating all the opportunities and working out what could be best applied to their farm and how.

The conservation projects shown in table 7.1 below were successful in attracting funding. These projects confirm that, if a range of simple management practices can be applied at the right scale, then income can be considerable.

Table 7.1 Funding from RSS conservation projects

Conservation work	Funding Available (per m or ha)	Extent of work on farm	Economic benefit
Hedge planting	£4.00	3800 m	£15,200.00
Fencing	£3.00	6000 m	£18,000.00
Wetland Management	£250.00	8 ha	£2,000.00
Water margins managed	£400.00	4 ha	£1,600.00
Grassland for nesting birds	£100.00	23 ha	£2,300.00
Grassland for wildflowers	£250.00	22 ha	£5,500.00
Grass margins on arable fields	£150.00	3.5 ha	£525.00
Sowing wild bird cover	£600.00	4 ha	£2,400.00
Total benefit			**£47,525.00**

Table 7.2 below uses an agricultural gross-margin[54] calculator provided by DEFRA to indicate how the income derived from these grants can be compared to previous

[54] Gross margin (GM) is not a profit figure; it takes no account of fixed or overhead costs such as labour, power, machinery, rent and so on. GM is output i.e. sales + subsidies (adjusted for replacement costs where required) less variable costs e.g. feed, sales, fertiliser, sprays, vet & medicines, etc.

inputs/outputs related to crop production. In this example 64.5ha of land was taken out of production. If this had been wholly devoted to growing milling wheat the area of land would have achieved a gross margin of £41,038. The RSS grants brought in £47,525.

Table 7.2 Gross margins calculation for winter wheat (milling)[55]

	£ ha	£ Total	Performance Details	
Enterprise output:			Hectares	64.5
Grain	616.25	39,748	Yield (tonnes/ha)	8.5
Straw	30.00	1,935	Yield (total tonnes)	548.25
Arable area payment (2004 only)*	225.00	14,513	Value (£/tonne)	72.5
Gross Output	871.25	56,196		
Variable costs:				
Seeds	40.00	2,580		
Fertilisers	80.00	5,160		
Sprays	105.00	6,773		
Sundry Crop Costs	10.00	645		
Total Variable Costs	235.00	15,158		
Enterprise gross margin	**636.25**	**41,038**		

In addition to implementing land use changes that have attracted funding, this farmer is particularly conscious of the need to protect the environment and strongly believes in rural stewardship in its broadest sense. Management practices go beyond schemes that have economic benefit. For example, well managed hedges and watercourses provide a network of wildlife corridors across the farm. A pond has been rejuvenated to benefit wildlife. Semi-natural woodlands are managed in such a way that allow public access, including a farm trail and future plans (at the time of interview) were to include a hide for winter bird watching and so further diversify.

Did the farmer think making these changes has compromised his core farming business? His reply was very positive:

55 Source: http://www.defra.gov.uk/farm/fbadvice/farm-accounting/gross-margins.xls

> *"Not at all – the areas of land chosen for change tended to be marginal. For example, I've spent years draining poor, wet boggy areas. Now they are managed as wetland with an annual management payment. The headland strips tended to be against woodland so crops were a bit dodgy there anyway. In addition, some of the works have enabled me to keep a man on – so it's a win-win situation".*

These projects not only brought environmental benefits to the farm but also socio-economic benefits to the local community. Implementing schemes such as those above require materials and labour e.g. hedging and fencing materials, seeds and so forth, that will be sourced from local businesses or contactors carrying out hedge planting, fencing, dyke repair and pond excavation. In a time when there is much concern about declining rural services and job losses, encouraging farmers to use local services can only be a good thing.

This example demonstrates what can be achieved given the time devoted to the investigation of funding opportunities. However, this farm is large. The land use changes took approximately 65ha land out of production, in this case just 10% of the land holding, and therefore it seemed that it would be without significant detriment to the economics of production. This had been an important factor in the decision-making process before deciding to go ahead with the application. However, farmers on smaller land holdings often feel they are unable to make such changes. Several of the farmers interviewed were critical of existing agri-environment schemes, stating they were of little benefit to the farmer with smaller land holdings. In section 7.4 the opportunities for implementing agri-environment schemes on a smaller farm enterprise will be examined.

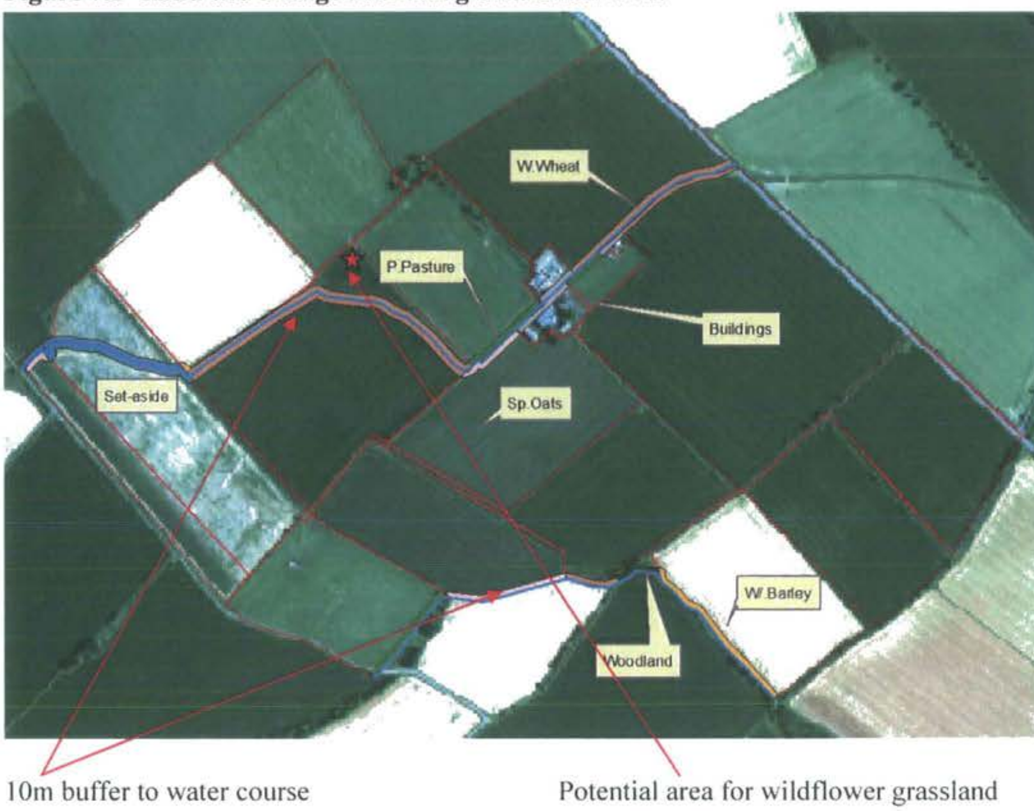
7.4 Agri-environment opportunities on a small farm

In this second case study the funding opportunities for a small mixed farm unit of approximately 100ha are examined. On this farm about 75ha are used to grow winter wheat, winter barley and spring oats. Eight hectares are currently under set-aside and 16 hectares are permanent pasture for 80 suckler cows (2.0 LU/ha) and 20 store cattle. There is a small amount of broadleaved woodland. This farm is located near monitoring site KR004, which has been shown to be particularly vulnerable to nutrient pollution. When interviewed this farmer was asked why he had not applied for funding under the RSS. He indicated that he had thought about making an application but had heard it was very difficult for small farmers to be successful and he found the information in the guideline very complicated. This farm is therefore suitable for the GIS methodology to calculate benefits and losses from land use change.

Remotely sensed data enabled an accurate land cover map of this farm to be illustrated in a GIS package. The field boundaries and water-courses overlaid a digital image to calculate the potential of changing land use. One of the major benefits of using GIS is that calculations relating to economic and environmental costs and benefits can be built into the attribute table. In addition, an advisor may not be familiar with the field layout of a particular farm and coupling the GIS with the use of aerial photography enables an overall view of the farm to be visualised. In this way the farmer and advisor can work together with an interactive map to discuss the merits of different land use changes.

For example, figure 7.1 below illustrates the layout and location of watercourses of this farm. The 2002 land use is shown and with the farmer's records and/or the use of RS data, the different land cover types were identified.

Figure 7.1 Land use change modelling on a small farm



A 10m buffer was applied to the watercourses, and calculations performed on each segment to ascertain the economic costs of taking those field segments out of arable production. In the calculations certain assumptions were made. In the first land use change scenario, costs were calculated for changes to fields with existing arable crops, the wheat, barley and oats. The variable costs of seed, fertiliser, sprays and other labour costs were averaged for each crop and taken to be the same as those quoted in the Farm Management Handbook (Chadwick, 2003) i.e. £235 per hectare. Grain output, was averaged at 8.5 tonnes/ha and £72.50 per tonne. In table 7.3 below, the net economic outcome on each buffer segment are shown. In summary, the 10m buffer to the water courses would take 3.29ha of land out of production. In terms of grain sales this would result is a loss of approximately £1300, but savings in seed, fertiliser and manpower costs amount to approximately £500 giving a net economic loss of almost £820. However, this calculation does not indicate the potential economic benefits that could be accrued if a range of schemes under the RSS were applied to the whole farm in a successful application.

Table 7.3 Economic change resulting from the 10m buffer

Land_2002	Buffer Ha	Input Savings £	Output Losses £	Net_loss £
W. Wheat	0.29	67.63	177.35	109.72
W. Wheat	0.15	35.75	93.75	58.00
Mixed Use	0.04	0.00	0.00	0.00
Perm. Pasture	0.06	0.00	0.00	0.00
Mixed Use	0.17	0.00	0.00	0.00
W. Wheat	0.45	105.40	276.40	171.00
W. Wheat	0.50	116.47	305.44	188.96
Perm. Pasture	0.14	0.00	0.00	0.00
W. Barley	0.05	11.73	30.77	19.03
Sp. Oats	0.11	24.92	65.34	40.42
Fallow	0.26	0.00	0.00	0.00
Fallow	0.26	0.00	0.00	0.00
Sp. Oats	0.04	10.04	26.33	16.29
Woodland	0.07	0.00	0.00	0.00
W. Barley	0.28	66.88	175.37	108.50
W. Wheat	0.07	17.56	46.04	28.48
Sp. Oats	0.20	47.95	125.73	77.79
Perm. Pasture	0.15	0.00	0.00	0.00
Totals	**3.29**	**504.33**	**1322.51**	**818.19**

In this land use change scenario, it is assumed that the farmer will apply for funding similar to that of the farmer in the pilot scheme. These include:

- A small field (marked by a star on the map) is permanently taken out of arable production and sown as grassland for wildflowers;
- Field boundaries will be replanted with hedgerows;
- The buffer zones will be fenced off and managed as a grass margin or beetle bank in arable fields.

Table 7.4 indicates that implementing these changes could potentially accrue an income of over £11,000.

Table 7.4 Potential benefits under RSS

Conservation work	Funding available / unit	Extent of work on farm (ha or m)	Unit	Economic benefit
Hedge planting	£4.00	3000	m	£1,200.00
Fencing	£3.00	3000	m	£9,000.00
Water margins managed	£400.00	3	ha	£1,200.00
Grassland for wildflowers	£250.00	1.25	ha	£312.50
Total benefit				**£11,712.50**

Although this example has shown significant economic benefits can accrue from changing land use even at the small scale, this is only a desktop study. The RSS scheme is highly competitive requiring the farmer to achieve a minimum threshold of points for a successful application. As these thresholds are not published, it is not known if the suggested changes to this farm would achieve enough points in the RSS and therefore receive the funding.

Since January 2005 there have been significant changes to way in which funding for the farming community is allocated. The direct support schemes have been abolished and are replaced by the Single Farm Payment. This payment is subject to statutory management requirements (known as 'cross-compliance') that promote a more environmentally friendly and sustainable approach to farming. These include some existing funding opportunities such as the Nitrate Vulnerable Zones action programme, which are discussed below and in section 7.6.

7.5 Funding for mandatory requirements

In response to Nitrate Directive (91/676/EC), the NVZ action programme is designed to reduce nitrate pollution to surface and ground waters. The main requirements are aimed at reducing the amount of fertilisers used and better matching usage to crop requirements. For example:

- Organic manures should not exceed 210 kg/ha N on arable fields (reducing to 170 kg/ha from 2006) and 250 kg/ha on grassland;

- There are closed periods for spreading slurries, sewage sludge and poultry manures;

- Farms in NVZs must have sufficient storage capacity over the closed period for these manures;

- Comprehensive farm records must kept on cropping, livestock numbers and usage of organic and inorganic fertilisers.

In order to help farmers comply with these regulations, there is a discretionary NVZ grant scheme. This is for installing or improving waste storage facilities but it does not cover maintenance of existing storage. Currently this is valued at 40% of capital net expenditure to a maximum of £85,000[56]. In reality though, SEERAD has a limited budget amounting to £17 million over three years[57]. With 12,000 farms in the Scottish NVZs, this equates to less than £1500 each, a sum the farming community feels is inadequate. A further complication to receiving the grant is that prior planning consent must be obtained, all work must be completed by 31st October 2005, and the farmer must submit a satisfactory Farm Waste Management Plan. The main beneficiaries of this scheme are livestock enterprises where slurry storage is a problem. The arable sector is not targeted. Furthermore, only farmers within a designated NVZ can apply and the number of successful applicants depends of the number within each tranche and the level of (undisclosed) resources available at that time.

So far we have seen that pre-2005 funding could provide opportunities for large farm enterprises to make significant changes to their day-to-day management practices and that this can have a beneficial impact to the environment. But, how will the post 2005 implementation of CAP reforms affect the farming community?

---

56 http://www.scotland.gov.uk/library5/agri/nvzg-01.asp
57 http://www.scotland.gov.uk/library5/environment/coch-00.asp.

7.6 CAP Reform: Single Farm Payments (SFPs) and Land Management Contracts (LMCs)

The most significant effect of CAP reforms to the farming community in Scotland is that there will now be two main funding opportunities: the Single Farm Payment (SFP); and the new Land Management Contract Scheme (LMC), the latter comprising 17 broad rural development measures funded by modulation.

The main aim of the SFP is to make the farming community more efficient and more market-orientated. To achieve this, farm payments will no longer be based on the number of livestock units or area under arable crops. The payment rate is based on the average of all subsidies and area of land included in historic IACS claims between 2000 and 2002. This provides a reference amount, and a reference area on which future SFP entitlements are determined. Although the intention of the SFP is that farmers can now pursue any agricultural activity they choose without their SFP rising or falling, there are conditions attached. These include:

- All eligible land must ‘be at the farmers’ disposal for a period of at least ten months’ with a defined 17-month period;

- Farm tracks, woodland, orchards and vineyards are not deemed to be eligible land;

- Certain activities are on a ‘negative list’ and are ineligible for the SFP, including strawberry, potato and vegetable production;

- Farmers must continue to meet the requirements of cross-compliance, i.e. the need to keep land in ‘good agricultural and environmental condition’ (GAEC).

Furthermore, payments will continue to be subject to modulation (6.5% in 2005, and 8.5% for 2006), plus a further 3% to fund the National Reserve[58]. In addition to

[58]“The ‘National Reserve’, deals with situations related to the switch from the coupled to decoupled subsidy regimes. It is designed to help farmers and crofters whose businesses, because of particular circumstances, would

these conditions, entitlements will be allocated in 2005, and those farmers who do not claim in 2005, will lose the opportunity to claim.

During the interview stage of this research, many farmers expressed concern over the implementation of the agreed CAP reforms and in particular the impact of changing funding to the Single Farm Payments (SFP) Scheme. Respondents stated that basing the SFP calculation on past claims does not reflect their current farming system, and payments will be too low. In contrast, an interview with SEERAD in December 2002 indicated its confidence that decoupling in Scotland would bring opportunities and benefits (both environmental and economic) to the farming community under the auspices of a global Land Management Contract Scheme.

The LMC concept has three tiers, which will be phased in over a period of two years from 1st January 2005. Tier One is a basic level into which all farmers will opt. It is stated as 'securing a basic level of environmental protection, food safety and animal welfare' corresponding to the Single Farm Payment and Cross Compliance[59]. Tier Two (also to be introduced in 2005) will 'deliver widespread benefits leading to economic, social and environmental improvements'. Tier Three to be phased in, in 2007, 'will deliver tailored benefits leading to economic, social and environmental enhancement' (SEERAD, 2005b). However, SEERAD has been criticised for its lack of consistency regarding information dissemination on option details, guidance and providing an application form to enter the LMC scheme. For example, James Irvine of Land-Care UK states:

> *'Here we are on the last day of March with the farm Spring work well underway and we still do not know the detail as to what LMCs are all about. And yet applications for this "tier 2 modulated" subsidy are to be lodged with SEERAD by 16th May 2005 at the very latest for the year 2004-2005. There are dire penalties for mistakes or omissions. Submissions relating to LMCs need to be made at the same time as that for the whole farm plan in relation*

otherwise be at a disadvantage by the sole application of the Single Farm Payment Scheme (SFPS)" http://www.scotland.gov.uk/library5/agri/sfps05il1-00.asp

59 Cross compliance requires farmers to practice more environmentally friendly methods of farming in order to receive their SFP.

to the Single Farm Payment (SFP) that is central to the new form of farm subsidy. (Irvine, 2005a)

This criticism is not without foundation. SEERAD had agreed to provide a speaker to a CAP reform seminar hosted by the firms Kemira GrowHow and Campbell Davis in February 2005, but the speaker did not attend on the grounds that 'new rules were about to be announced ... SEERAD did not wish to confuse or mislead anyone so they preferred to stay away' (Irvine, 2005b). Furthermore, the well advertised cut-off date for submitting an LMC application was given as 16th May, but the guidance document and application forms were not published until 12th April 2005. The LMC menu options document is 68 pages long, setting out detailed guidance on what is and is not permitted within each of the menu options. In addition an eight page application form must be completed with the declaration section stating:

'I have read the LMCMS Notes for Guidance (LMCMS1) and understand the rules of the scheme and will abide by the management requirements for at least 5 years where necessary'.

Publishing such an important document at a time when farmers are particularly busy, suggests that farmers' comments that SEERAD has little understanding of farm management or the time scale required in planning a five-year commitment, have foundation. It is not reasonable to expect farmers to read, digest, and make informed decisions on what options to choose within such a short space of time. Large agri-business enterprises that employ clerical staff may be able to cope with such a short time scale, but the small family farm unit will find this task challenging. In response to growing concern from the farming community a press release from SEERAD on 9th May (Scottish Executive, 2005) announced that the SAF/IACS form submission deadline would be extended to 10th June. The LMC application date has also been extended to 6th June 2005. However, farmers who submit claims between 16th May and 10th June will be penalised, 'and applications received after 10th June would be rejected.' The SEERAD press release states:

'If IACS forms are not returned on time, substantial late penalties will apply to any SFPS claims received after 16 May 2005 and up to 10 June 2005'. (SEERAD, 2005a).

Clearly the farming community was under pressure to submit applications for the SFP and further funding but the National Farmers' Union President interviewed on BBC Radio 4's Farming Toady programme on 13th May stated the system was in "utter chaos" (BBC News, 2005), further stating that the helpline set up to help farmers is permanently engaged.

Farming throughout EU is now the subject of strict regulation, including management practices that have a direct impact on water quality. The CAP reforms were agreed in 2003, giving a lead time of two years to put in place guidance and support that could have provided opportunities for the farming community to make positive changes to land use practices. This would have given farmers more time to consider planning for a sustainable economic and environment enterprise. However, the late publication of such guidance suggests that SEERAD is not fully committed at this time to promoting such a notion.

7.7 Can farmers' day-to-day practices be modified to improve water quality?

The water quality monitoring has shown nitrate pollution continues to be a problem in the Leet catchment. Modelling has demonstrated that changing land use can reduce this impact, and that there are funding opportunities to make such changes. However, there remain barriers to farmers taking up such land use change opportunities.

Many of the barriers are related to socio-economic and institutional factors. For example, the postal survey and interviews highlighted the views of the farming community. It was clear from the interviews that some farmers were keen to keep up to date with new technology and more willing to take the time to investigate funding opportunities. However, these were the farmers who had been educated to college level and more familiar with research techniques. The older farmers particularly those over the age of 50 were less inclined to make significant changes to their farming practices. In addition, where the older farmers had smaller land holdings they were even more reluctant to make changes. Indeed two of the farmers who were very close to retirement age (coincidentally both single men who had no immediate family to hand the farm on to) stated they would be very reluctant to implement new requirements if it meant significantly changing their current practices. It was found later that one of these two has since sold his land holding and taken the opportunity for retirement.

In practice, the uptake of policy decisions can be grouped in categories of barriers. These include:

- ***Lack of awareness.*** Farmers generally are more aware of soil-related problems. They can see the effects of soil erosion and siltation in ditches and on roads, but diffuse pollution is less obvious and by nature it is difficult to pin-point its source. Therefore a farmer may not know that he/she is contributing to the problem in the catchment. In addition, many still think that water quality problems are associated with point sources, e.g. use of washing powders and discharge from sewage treatment works.

- ***Farmer scepticism.*** There is a degree of mistrust among farmers. Some think government agencies have ulterior motives – e.g. they think that EU regulations are 'gold plated' (made more stringent) at national level and that some policies are designed to benefit larger land holdings and ultimately drive the small farmer out of business.

- ***Lack of willingness.*** In a time of poor economic return, falling commodity prices, and rises in input costs (e.g. fuel / wages), farmers do not necessarily give diffuse pollution issues a high priority. Several of the farmers stated that, if they had more cash to spare, they would like to plant more hedges, fence off water courses, reduce stock levels and so forth.

- ***Limited ability.*** In the Leet catchment the average age of farmers is 57. Many feel they do not have the necessary skills or ability to take on board some of the new methods, particularly the requirements of on-line recording. Several of the farmers said they would like to have specialist training in the general use of computers and in the use of relevant software packages in particular.

- ***Impracticality of measures.*** The literature on management measures is often very long-winded and often is sent out at inappropriate times. Not only is it difficult to find the time to read and digest the requirements. But many farmers believe that their farm is not represented and it is difficult to see how to adapt the measures to their particular operation.

- ***Cost.*** Recent changes to funding from the EU and SEERAD have not been properly presented to the farming community therefore the full range of available opportunities is unknown.

- ***Effectiveness.*** Many farmers are unsure about the potential benefits and effectiveness of some schemes or changes to day-to-day practices. It is important that farmers are given access to demonstration sites, with the full back-up of information to help them assess benefits that may be applicable to their farm.

- ***Knowledge transfer.*** The key informer in Scotland is SEERAD, but it has been demonstrated that there is a lack of leadership from Government. Advisory agencies and other interested organisations feel they cannot deliver good quality advice when this is not available.

7.8 Summary

The findings from this chapter reveal that one of the main concerns for the farming community is the change in the way funding from the EU community is now presented. Before January 2005, there was a wide range of direct support payments funded from the CAP budget. These guaranteed a certain level of farm income aimed at different methods of farm production. Voluntary agri-environment schemes such as the RSS, although not specifically intended to improve water quality, provided opportunities for substantial payments in return for making changes in day-to-day land management practices promoting habitat enhancement. Two case studies showed the type of changes beneficial to improving water quality that could be implemented. However, such schemes were criticised by the farming community and some advisors, as being very complicated and so were difficult for farmers with small land holdings to make a successful application even after several attempts.

Implementing changes directly related to improving water quality, such as, the mandatory requirements of the NVZs have also been criticised. Funding is from a limited budget and targeted at improving or providing new slurry storage facilities, ignoring the needs of the arable sector.

Farmers do not intentionally pollute water courses. They would like to make improvements to their day-to-day management practices, but in an economic climate where commodity prices and therefore farm incomes are falling, they find this very difficult to do so without some sort of support. The changes brought about by CAP reform could have provided many opportunities for funding such changes. Initially SEERAD was very optimistic about decoupling and the introduction of the LMCs. However, as the date (May 16th 2005), for claiming the SFP and choice of LMC menu came and went, it was clear that SEERAD had not fulfilled its obligations and did not have the necessary information in place on which decisions could be made.

There clearly are barriers to farmers implementing land use change to benefit water quality. These have not only been economic but also institutional as described in section 7.7. The Water Framework Directive requires 'good ecological status' to be achieved. If real progress is to be made in meeting this target, Government must take some responsibility for putting in place or improving institutional opportunities such as adequately funded advisory agencies whereby reliable and appropriate information can be transferred to stakeholders to help them make necessary changes.

Chapter Eight:

Evaluating the impact of land use and policy on water quality in an agricultural catchment: conclusions and recommendations

8.1 Introduction

The aim of the final chapter is to discuss how the thesis contributes to research knowledge and in particular how the objectives and research questions bulleted below meet this requirement. Chapter One, began by stating how this research methodology differs from traditional approaches. This was achieved by applying an interdisciplinary approach from natural and social science methodologies to understand how stakeholders' knowledge and understanding of EU water quality legislation and the decision making process can be applied to scenarios of land use change at the field-scale within a nutrient export model. An overview of the extent of the nitrate problem focused on the Leet Water catchment. The physical characteristics and socio-economic nature of this catchment (described in section 1.2.3) made this an appropriate study site. Furthermore, because this is a period of transition in the way EU legislation will impact on day-to-day farming practices including subsidy payments and grants, it was important to know how stakeholders in a real landscape setting would react to these changes. From this, gaps in existing research were identified enabling the following research objectives to be posed:

- To identify and evaluate relevant EU policies for water quality and river basin management;

- To ascertain the views of members of the farming community and other stakeholders to assess the possible impacts of existing policies;

- To assess the potential of multispectral remote sensed data for mapping precise land cover at the field scale including the ability to distinguish winter and spring sown cereal crops;

- To develop a geographical information system (GIS) of land cover structures and patterns as a tool to allow pollution impacts to be modelled using the best available data sets;

- To model scenarios of landscape change and thereby identify and evaluate the sustainability of landscape structures that regulate nutrient flux under different farming systems.

The literature review (Chapter Two) identified and described the EU policies intended to address the issues of nitrate pollution in agriculture. It was found that the requirements of the Water Framework Directive and Nitrate Vulnerable Zones will have an increasing impact on agricultural communities, and that there have been major changes in the number and in the way government funded options designed to address the water quality issue are presented to the farming community (described in Chapter Seven). Academic research and the practical applications of water quality models have found that nitrogen flux models are well developed and reasonably well understood. In section 2.2 the research found that there are many sophisticated models now available to the research community. Table 2.4 summarises the characteristics and range of options available. These are generally described in terms of processes, spatial and temporal dimension and, data requirements. In addition, the potential of riparian land and vegetation to act as a buffer zone for nutrient flux is also well understood. The conclusions from the literature review led to the decision that this research would evaluate tried and tested models such as INCA and the export coefficient approach to model the impacts of existing land use and land use change scenarios on water quality (Jarvie *et al.*, 2002; Johnes, 1996; Johnes and Heathwaite, 1997; Whitehead *et al.*, 2002; Whitehead *et al.*, 1998a; Whitehead *et al.*, 1998b) (described in Chapter Six). This evaluation found that the export coefficient approach was the most suitable model for assessing the impacts of land use change scenarios at the field scale. Studies using Remote Sensing for agricultural land cover classification indicated there was further need to investigate the ability of image classification techniques to produce precise land cover maps for the integration in land use decision-making modelling (described in Chapter Five). As a result, aerial photography and multi-spectral data (Airborne Thematic Mapper) covering the extent of the study area were acquired from the NERC Airborne Remote Sensing Facility.

The literature on decision making and perception studies and, in particular, the Australian Landcare approach (described in section 2.6), showed that the traditional top-down approach to adopting new ideas relating to land use management produces 'laggards', but that the integration of a bottom-up approach has much to offer the success of the river basin management planning process. This is an approach that has not been adopted in the UK. Understanding the Australian approach helped develop the framework of the interviews conducted with stakeholder groups.

As a result of the literature review and results of the long-term water quality monitoring by SEPA a key question was posed in Chapter Four:

- Why, despite 20 years of water quality legislation is there still a nitrate problem in the Leet Water catchment?

Section 8.2 of this chapter summarises the findings of this research in relation to the key question (section 8.2.1), then specifically addresses the social science aspects in section 8.2.2 (relating to questions 1, 2, and 3 below) and the natural science aspects (questions 4 and 5) in sections 8.2.3 and 8.2.4.

1. Can policy designed to improve water quality be implemented in a small catchment?

2. To what extent does farmers' knowledge and day-to-day farming practices contribute to poor water quality in the Leet catchment?

3. To what extent does the knowledge transfer process affect successful implementation of policy decisions?

4. Can an accurate high-resolution agricultural land cover map at field scale be derived from Remote Sensing imagery?

5. To what extent can established water quality models such as INCA and the export coefficient approach predict the impacts of changing land use and management practices?

8.2 Addressing the research questions

8.2.1 Why despite 20 years of water quality legislation is there still a nitrate problem in the Leet Water catchment?

The descriptions of the monitoring sites in Chapter Three showed this catchment has a long history of poor water quality. Further monitoring undertaken during the research period confirmed that poor water quality continues to be an important issue in the catchment and the EU maximum water quality limit of 11.3 mg/l NO_3-N has been exceeded on many occasions (Table 1.1 and Figure 1.4). Chapter Two (section 2.5) confirmed that it is now accepted that agriculture makes a significant contribution to poor water quality. Why does this trend of poor water quality continue? This research concludes that it is a result of a complex set of circumstances surrounding farming practice. The significant contributors to poor water quality from agriculture are the factors that lead farmers to practice their farming in a particular way. Of particular importance are the consequences of long-term EU funding through the CAP farm payments and the production subsidies system. These subsidies (and in particular those for grain output) contributed to farmers developing a particular mind-set in which they felt increased profitability and high agricultural output were the only way to continue as economically viable units. This drive for increased profitability led much of the farming community to ignore the environmental consequences of their actions. The Leet catchment is an area underlain by heavy soils naturally unsuited to cereal production. To benefit from CAP subsidies, many farmers changed their output from low production barley and livestock to intensive arable production. This was achieved by changing their land management practices and making physical changes to the landscape. This included: the under-draining of fields to remove excess moisture content, making the land more suitable for wheat cultivation; removing hedge rows and field margins to make fields sizes more suitable for large machinery; and increasing the use of fertilisers to maximise grain output. The effects of these changes have been described in Chapter Three. Many farmers in the UK, including those in the Leet catchment area initially benefited from a higher standard of living and income. However, eventually the increased agricultural output led to a decline in commodity prices and farm incomes which contributed to the downward spiral of water quality. This deterioration was exacerbated as farmers further increased fertiliser inputs without due regard to the environment. Although the policies resulting from the 1989 Water Act were intended to improve water quality, they were not enforced rigorously. Furthermore, Government funding to promote positive changes in management practices was not uniform across the UK nor applied consistently. By the late 1980s, farm incomes were at as such a low level that many farmers believed they no longer had the means to undertake voluntary changes to their day to day farming practices that would have a beneficial impact on water quality.

During the 1990s there was a radical change in the way in which the Government and the public viewed the environment, including the quality of surface waters. The activities of the farming community came under close scrutiny following the crises of BSE (during the late 1990s) and the Foot and Mouth outbreak of 2001. Caring for the environment and in particular food production achieved a much higher profile not only at the local, but also national and international scales. Public organisations voiced their belief that it was no longer acceptable for individuals or businesses to pollute the environment without being responsible for their actions. In terms of agriculture the Government response was to introduce a complex system of voluntary grants and agri-environment schemes for which farmers could apply. These have been described in Chapter Seven. However, evidence from this study has shown that entry to such schemes and grants could be very difficult, or even inappropriate for small farms. Funds were limited and the related documentation overly long and difficult to understand so sections of the farming community (in particular those with small family-run farms) felt that access to funding for the schemes was in effect denied and they were prevented from making significant land use changes that would benefit the environmental quality of local water courses.

With a legacy of very poor water quality, the introduction of the WFD across the EU and expansion of the NVZs are the key policy instruments that take water quality issues seriously and must now be rigorously enforced.

8.2.2 Addressing the social science aspects - policy implementation; knowledge transfer processes and day-to-day farming practices

The conclusions of Chapter Four relating to research questions 1, 2 and 3 above revealed that farmers do not intentionally pollute water-courses. In fact they would like to make improvements to their day-to-day management practices. However, in an economic climate where commodity process and, in turn, farm incomes are low, farmers find this very difficult to achieve without some sort of financial support. One of the main concerns for the farming community in the Leet catchment was the change in the way funding from the EU community is now presented. Direct support payments were funded from the CAP budget. These guaranteed a certain level of farm income aimed at different methods of farm production. Although the pre-2005 schemes were heavily criticised as being difficult to enter, the key schemes described in Chapter Seven, including the RSS, provided opportunities for substantial payments in return for making changes in day-to-day land management practices promoting habitat enhancement as well as improving water quality. The two case studies illustrated in sections 7.3 and 7.4 outlined the type of land use changes that could be implemented to improve water quality. However, section 7.7 showed that the opportunities for making changes that are directly related to improving water quality such as the mandatory requirements of the NVZs are restricted. These were criticised not only by the farming community but also by the advisory services and other interested environmental organisations. At present, funding for such improvements is from a limited budget and targeted at improving or providing new slurry storage facilities for the livestock industry, thus ignoring the needs of the arable sector. It is not disputed that cattle, and in particular dairy herds, contribute significant pollution. However, this is an NVZ catchment with a high level of nitrate added from intensive arable farming. The question of how to support both farmers and the environment is a situation that must be addressed by Government in the near future if policy objectives are to be taken seriously.

There are other barriers to farmers implementing land use change to benefit water quality. These are not only economic but also institutional, as described in section 7.7. The Water Framework Directive requires 'good ecological status' to be achieved by 2012. CAP reform introduced the Single Farm Payment scheme linked to environmental objectives. This should provide many opportunities for meeting the WFD target. Initially SEERAD were very optimistic about decoupling, hailing the Three-tier Land Management Contract as the key scheme in Scotland to rationalise previous agri-environment. However, SEERAD did not fulfil its obligations for facilitating the claim of SFP or choices from the 'menu' of LMC. The necessary information was not in place from which informed decisions could be made.

The views of stakeholder groups highlighted significant issues for the successful implementation of the requirements for WFD and the NVZ action plan. The key problem was poor knowledge transfer. Some stakeholder groups (the farmers and advisors) believe there needs to be a radical re-think on the part of Government in the way in which documents relating to water quality are delivered. This includes moving away from documents that are overly lengthy, and delivered at inappropriate times, e.g. during spring when farmers (both livestock and arable) are particularly busy and can't find time to read them. They believe knowledge transfer can be increased by improving access to guidelines. Relevant literature must not be couched in jargon, but written in language appropriate for the farming community and in a form that can be easily read. It must be made available in a variety of formats. For example, some farmers suggested a simple folded A3 sheet outlining the main points. This should be followed up with further reading and clarification from web-based documents.

Although the knowledge gap was discussed with, and acknowledged by SEERAD during interview, these implications have not yet been fully addressed. As the requirements of WFD and the NVZs begin to take effect, this is an important issue that the policy makers and regulators will need to address urgently if water quality is to be improved within the next decade. The Australian Landcare model indicates that facilitators have immense potential to reach local communities and there can be a two-way process of exchanging knowledge and ideas. Figures 2.9 and 2.10 described the links between policy, technical data and stakeholder attitudes. These models demonstrate how barriers between the different groups can merge and dialog between the groups can take place. In this catchment there are potentials for developing a bottom-up approach. For example, the farming community 'know' their local area, and know where particular problems need addressing. The Leet Catchment Management Group (LCMG) exists, but it is not sufficiently proactive. Attendance at a LCMG meeting revealed a top-down delivery from SEPA and the SAC. This was very much in the vein of: "We are the experts. This is the problem. This is what we think you should do...". If the local farmers took the lead in this group they could set their own agenda. For example, by making demands of advisors and the regulators (including SEPA and SEERAD), to deliver information in a readily accessible format. A stumbling block in this approach is that many farmers think they are too small to be heard by Government. However, a local organisation, The Tweed Forum (the group instrumental in drawing up the Tweed River Basin Management Plan), has built up strong links between various stakeholder groups whilst maintaining a neutral stance. These links now need to be taken further. This organisation has the potential to become a gateway for knowledge transfer between Government, the regulator and the farming community. There has already been some useful work in the form of habitat enhancement demonstration sites locally and these should be more developed and funding made available for this purpose. Furthermore, The Tweed Forum should take on the role of the facilitator as described in the Landcare approach, receiving or seeking out new information and disseminating this to the farming community in terms they understand thus breaking down the knowledge gap. This is a practical application and could be a key opportunity for this group of stakeholders to take on a more proactive role as changes in regulations that impact on day-to-day land management practices and water quality become more apparent.

This section of the research clearly identified many concerns of the farming community relating to EU water quality legislation and good farming practice guidelines. This information was made known to SEERAD and it is hoped that they will act on it to benefit the wider community.

8.2.3 *Addressing natural science aspects 1: The use of Remote Sensing imagery for agricultural land cover mapping*

Producing the field scale land cover map was a key objective of this research (question 4 above). In Chapter Five it was shown that manual data collection across the catchment could not classify all the fields due to access problems and this can be a limiting factor in data acquisition for the land use change scenario modelling. Although high quality land cover data is collected through the June agricultural census, as are data for the British Survey of Fertiliser practice, these are not available to the research community at the field scale. This poses a significant problem for modelling in terms of consistency and quality of data. Therefore, alternative techniques for gathering consistent high quality data (for land cover) needed to be evaluated. This led to the research to apply for funded, remote sensed data from the NERC Airborne Remote Sensing Facility, which provided the aerial photographs and multispectral digital imagery covering the extent of the catchment. Non-expert individuals could be trained to manually classify land cover from the aerial photographs with a precision of 87% on a small sample of fields. However precision could be improved by cross-checking and sharing knowledge on what land cover was in areas of uncertainty. This method of classification was scaled up to provide an effective method of collecting data on land cover in a small catchment. The level of precision of the land/crop cover map produced by remotely sensed imagery was 82%, comparable to the manually classified map. Although RS imagery has the potential to save time and money for land use mapping, in reality there is a trade off between scale and precision. Previous research (Cherrill *et al.*, 1995) has produced large scale land cover maps at the 25m pixel scale. Higher resolution maps have also been produced (Binaghi *et al.*, 1996; Foody, 2000; Hill *et al.*, 2001), but these classified land cover into fewer distinct groups and did not break arable land into crop types. Previous research has also focused on the Compact Airborne Spectrometer Instrument (CASI) has been used to classify land cover at the field scale (Aplin and Atkinson, 2001; Thomson *et al.*, 1998), but these results only classified eight land use classes including urban areas. In this research, section 5.7.4 describes the results from a different sensor. Data acquired from the Airborne Thematic Mapper (ATM) has successfully been combined with a set of user defined decision tree algorithms to classify land cover. This technique was able to distinguish winter and spring sown cereal crops. However, it was found that this method was not without problems. The advantage of using RS data compared to aerial photography is that a larger land area can be classified using the same training set with relatively little extra computational time and so large scale maps (e.g. regional or national) can therefore be produced classifying broad land cover types. However, crop type maps produced at the field scale maps are much more problematic.

In this study, the first issue was that only approximately half of the RS imagery acquired could be used because of cloud cover. The classification map had to be limited to the Lambden Burn sub-catchment and lower Leet as cloud-cover and cloud-shadow over the upper reaches of the Leet obscured the surface preventing detail of individual fields to be classified.

The second key problem for producing precision land cover maps at the field scale is that arable crops and in particular woodland have complex spectral signatures. This is most apparent where clustering of pixel values in each land cover type overlap. The issue in question was resolved by combining supervised classification methods to identify training areas with the hierarchical Decision Tree Classifier. This method has shown that user-defined expressions drawing on different combination of pixel values in more than two bands can provide unique signatures to differentiate major crop types and in particular the winter and spring sown crops.

However, determining the best training set was very time-consuming. This method would only be more efficient than the use of aerial photographs where very large areas of land cover need to be classified. Furthermore, RS can only be really effective if cloud-free data can be acquired and this must be at a time when there is sufficient difference in the growth stage of vegetation types so that a unique spectral signature can be recorded. Given the variable nature of the British weather during the summer months this is a significant limiting factor on the use of RS data.

This research has been valuable because it has highlighted significant practical limitations of RS imagery for high resolution land cover classification. This is most appropriate as currently the EU Monitoring Agriculture with Remote Sensing (MARS) programme is working towards the development of high resolution imagery to determine agricultural plot boundaries. The programme aims to support the farming community. It intends to provide high resolution digital maps to help farmers complete their CAP payment application forms more accurately, and, in addition, by identifying actual land cover it will help combat fraud. The NVZ regulations will also require very high quality land cover data as part of its monitoring and risk assessment requirements. Therefore, it is important that further research is undertaken into the improving spatial resolution and seasonal coverage of RS imagery across the UK that will help address CAP and NVZ monitoring.

8.2.4 Addressing natural science aspects 2: using INCA and the export coefficient approach to predict the impacts of changing land use and management practices?

In meeting the objectives of the study, land use and decision making factors needed to be brought together. The literature in Chapter Two and Chapter Six suggested that INCA could be successful at modelling the impacts of land use change related to decision making at a variety of scales. However, the results of section 6.4 demonstrated that INCA could not be adequately calibrated for the Leet catchment. There were several reasons for this. The conclusion was that the size of the water courses in the catchment was a limiting factor. It was also found that INCA does not indicate what is happening within an individual field, or identify those fields that are particularly vulnerable to nutrient loss other than by grouped land use. Again this is a limiting factor in a study where high resolution mapping is required. For example, concerned stakeholders, wanting to consider the impacts of the land use change scenarios, would find this larger scale difficult to work to. Users may want to know the impacts of reducing arable production by 10% at the farm scale, but this is not possible at the present time with this model.

A major limitation of the INCA model in this context is data availability. Although INCA is said to use readily available and inexpensive data sets (section 6.4.2) (Whitehead *et al.*, 1998a; Whitehead *et al.*, 1998b), in reality these are difficult and costly to acquire. Although the long term water quality data were available to the research at no direct cost, this was only because there was a strong between the Durham University Geography Department and SEPA. Had this relationship not been in place then the data would have had to be purchased; The MORECS data cost approximately £200. Base flow index values are recorded in an out of print book, and had to be obtained by personal correspondence with the Macaulay Institute. The OS digital data for defining the reach structure and field boundaries were obtained through the CHEST agreement, but took considerable time to correct and make it usable in the GIS.

The export coefficient approach proved to be a much more useful tool for modelling impacts of land use change. This approach also claims to have minimum data requirements. It does use less data than INCA. The field boundaries and river structure were already available, as were fertiliser rates for the different land use types, and it was a relatively simple task to find export coefficient values in the literature. However, it is not known how accurate the coefficient values were for the Leet catchment and, without expensive field work to measure true values, this is a limitation of the modelling carried out. Nevertheless, this research found that modelling predicted nutrient losses at the field scale using a modified export coefficient approach did identify particular land use types that contribute most to the water quality problems and those that are potentially vulnerable (section 6.3). Using the data, a risk assessment was applied to each field plot in the catchment and the land use change scenario modelling has shown that radical change is not always necessary to have an impact on water quality. Small changes to existing farming practice, such as reducing fertiliser use, can have an impact on the risk associated with each field plot. This level of information would be very useful to the farming community as it would help allay their fears that water quality can only be improved by large scale changes.

The export coefficient approach has potential to be extended and used by a wider community. It is a minimum data input model. It has a simplicity which makes it easy to use and understand. Further research and the development of computer program scripting such as VBA coding could enable the incorporation of a user-friendly interface to be included. This would enable land cover type to be changed on a field by field basis and/or fertiliser inputs changed interactively. The built-in export coefficient equations would then return a new set of scenarios maps to demonstrate the change in predicted outcome of nutrient loss. If these limitations can be overcome, this type of simple, interactive, decision support modelling should be available on a web based interface, freely available to local stakeholders.

8.3 Summary and recommendations

The research has differed from most water quality studies in that it has examined the issues from an interdisciplinary approach. This has brought together natural and social science methodologies and that required the development of specialist research skills. This was very ambitious as it required the use of digital image processing and GIS software packages in addition to the understanding of water quality models for the natural science methodologies and the design and implementation of a postal survey and interviews for the social science methodology.

However, the strength of this approach is that, by bringing together these two strands of science, this researcher was better able to understand why the water quality problem in the catchment persists. For example, during the interview process with stakeholders it became clear that there are barriers and mistrust between 'lay people', 'politicians' and 'scientists'. Each group often believes that the others have something to hide, or deliberately use language that can be interpreted in different ways. In particular the farmers are suspicious of scientific models as they do not always understand the methodology, calculations or even the language used in their interpretation. Indeed, they are confused about the usage of the figures 11.3mg/l and 50mg/l and do not understand the context in which both are used as a permitted maximum of nutrient leaching. Furthermore, some of the farmers interviewed could not understand how the NVZ boundary was derived, and in particular why it drawn in places that can divide a single farm into areas where some fields are within and others outside the boundary. These examples confirm there is need for consistency and transparency in the interpretation and discussion of the science behind decisions.

One of the key issues resulting from this research is confirmation of the lack of confidence stakeholders have in governmental institutions. Stakeholder groups including advisors and the farming community criticise Government for their inability to deliver agricultural guidelines and information on funding opportunities that are timely and directly relevant to their needs. In the very near future, the farming community and advisory organisations will play a crucial role in helping to meet water quality standards required by the WFD. Government bodies such as SEERAD may make the policy decision and provide guidelines and regulatory agencies such as SEPA have to enforce these, but there needs to be a radical re-think in the way information is delivered. For example there will need to be local facilitators that understand local issues and understand the needs of the agricultural community. The Australian Landcare approach recommends tackling difficult environmental issues by involving stakeholders in a participatory, bottom-up approach. This is an area that needs consideration.

8.4 Limitations of the research

One of the main limitations of the research has been the extent of the land use scenario change modelling. Due to the problems encountered in obtaining data sets and calibrating existing models, it was not possible to carry on with this as far as intended within the research period. The modelling was severely restricted by the availability of data sets. In terms of data for the precision land use mapping and fertiliser practices this could be improved. Farmers already produce fully annotated land cover maps and livestock levels as part of the annual return to SEERAD in order to claim their single farm payments. Similar data form part of the annual agricultural census. Detailed data on fertiliser practice are returned to the Quality Assurance Schemes, or gathered for official statistical purposes such as the British Survey of Fertiliser Practice. The data are there, but they are just not freely available to the research community. If SEERAD (DEFRA in England & Wales) is serious about wanting to support the farming community in its attempts to comply fully with the regulations defined in water quality legislation such as the NVZ of WFD, there must be a will on the part of Government agencies to make such data at the appropriate resolution available to the research community.

8.5 Implications for further research

This research has achieved the objectives set out in section 1.4, and answered the research questions of section 4.1. However, it is believed that there is scope for taking this research forward. First, it is strongly recommended that the risk assessment modelling technique described in section 6.3.4, addresses the limitations described in 8.2.4 and is taken further. Secondly, the resulting model should be made available to the farming community in the Leet catchment. Furthermore, this interdisciplinary approach has much to commend it. Using social science methods to examine what has previously been regarded as being in the natural science domain has highlighted many issues, particularly that of knowledge transfer between Governments, the scientists and the lay community.

As more legislation tries to cope with different environmental problems across an enlarged EU, this supranational body will rely more heavily on 'hard scientific fact' as a basis for formulating decisions and policy making. If stakeholders from all sections of society are to 'trust' the scientific facts, research into methods to breaking down the barriers as described in section 7.7 is imperative. This is an absolutely key area of research that must become more prominent in the future. It is in this area that the joint studentship scheme of ESRC/NERC can contribute by funding further interdisciplinary research.

Bibliography

Addiscott, T.M., 1996. Fertilizers and Nitrate Leaching. In: R.E. Hester and R.M. Harrison (Editors), Agricultural Chemicals and the Environment. Issues in Environmental Science and Technology. Royal Society of Chemists.

Addiscott, T.M., Whitmore, A.P. and Powlson, D.S., 1991. Farming, Fertilizers and the Nitrate Problem. CAB International, Wallingford.

Adinarayana, J., Flach, J.D. and Collins, W.G., 1994. Mapping Land Use Patterns in a River Catchment using Geographical Systems. Journal of Environmental Management, 42: 55-61.

Aplin, P. and Atkinson, P., 2001. Sub-pixel land cover mapping for per-field classification. Int J. of Remote Sensing, 22(14): 2853 - 2858.

Aplin, P., Atkinson, P.M. and Curran, P.J., 1999. Fine Spatial Resolution Simulated Satellite Sensor Imagery for Land Cover Mapping in the United Kingdom. Remote Sensing of Environment(68): 206-216.

Arheimer, B. and Olsson, J., 2002. Integration and coupling of hydrological models with water quality models: Applications in Europe. Swedish Meteorological and Hydrological Institute (SMHI).

Armstrong, A.C. and Burt, T.P., 1993. Nitrate Losses from Agricultural Land. In: T.P. Burt, A.L. Heathwaite and S.T. Trudgill (Editors), Nitrate: Processes, Patterns & Management. Wiley.

BBC News, 2005. Farmers' EU subsidies 'shambolic'. news.bbc.co.uk.

BGS, 2001. Groundwater nitrate vulnerable zones for Scotland, British Geological Survey.

Bibby, J.S., 1982. Land capability classification for agriculture. Macaulay Institute for Soil Research, Aberdeen.

Binaghi, E., Brivio, P.A., Chezzi, P., Rampini, A. and Zilioli, E., 1996. A hybrid approach to fuzzy land cover mapping. Pattern Recognition Letters, 17(1996): 1399-1410.

Boorman, D.B., Hollis, J.M. and Lilly, A., 1995. Hydrology of Soil Types: a hydrologically-based classification of the soils of the United Kingdom. Report No. 126, Institute of Hydrology.

Bouraoui, F., 1995. Development of a Continuous, Physically-Based Distributed Parameter, Nonpoint Source Model, Agricultural Department, Virginia Polytechnic Institute and State University.

Braskerud, B.C., 2002. Factors affecting nitrogen retention in small constructed wetlands treating agricultural non-point source pollution. Ecological Engineering(18): 351-370.

Brezonik, P.L., Easter, K.W., Hatch, L., Mulla, D. and Perry, J., 1999. Management of Diffuse Pollution in Agricultural Watersheds: Lessons from the Minnesota River Basin. Water Science & Technology, 39(12): 323-330.

Burt, T.P., 1993. Nitrate as groundwater contaminant. In: T. Burt, A. Heathwaite and S. Trudgill (Editors), Nitrate, Processes, Patterns and Management. Wiley, pp. 213 - 238.

Burt, T.P., Heathwaite, A.L. and Trudgill, S.T. (Editors), 1993. Nitrate: Processes , Patterns and Management. Wiley.

Burt, T.P. and Johnes, P.J., 1997. Managing Water Quality in Agricultural Catchments. Transactions of the Inst. British Geographers, 22(1).

Burt, T.P., Matchett, L.S., Goulding, K.W.T., Webster, C.P. and Haycock, N.E., 1999. Denitrification in riparian buffer zones: the role of floodplain hydrology. Hydrological processes, 13: 1451 - 1463.

Burt, T.P. and Trudgill, S.T., 1993. Nitrate in groundwater. In: T.P. Burt, A.L. Heathwaite and S.T. Trudgill (Editors), Nitrate: Processes , Patterns and Management. Wiley.

Butterfield, D., Wade, A.J. and Whitehead, P.G., 2004. INCA user guide, unpublished.

Campbell, A., 1997. Facilitating Landcare: Conceptual and practical dilemmas. Centre for Rural Social Research, Charles Sturt University, Australia.

Carr, A., 1994. Grass-roots and green tape: community-based environmental management in Australia (unpublished PhD Thesis), Centre for Resource and Environmental Studies, Australian National University, Canberra.

Carton, O.T. and Jarvis, S.C., 2001. Nitrogen and Phosphorus cycles in Agriculture. In: P. De Clercq et al. (Editors), Nutrient Management Legislation in European Countries.

Chadwick, L. (Editor), 2003. The Farm Management Handbook 2003/04. Scottish Agricultural College, Edinburgh, 548 pp.

Cherrill, A.J., McLean, C., Lane, A. and Fuller, R.M., 1995. A comparison of land cover types in an ecological field survey in northern England and a remotely sensed land cover map of Great Britain. Biological Conservation, 71: 313-323.

Chess, C. and Purcell, K., 1999. Public Participation and the environment: Do we know what works? Environmental Science & Technology, 33(16): 2685-2692.

Chrisman, N., 1997. Exploring Geographical Systems. Wiley.

Collentine, D., Forsman, A., Galaz, V., Kallner Bastviken, S. and Stahl-Delbanco, A., 2002. CATCH: decision support for stakeholders in catchment areas. Water Policy, 4: 447-463.

Cook, R.J., 1997. The potential impact of buffer zones in agricultural practice. In: N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Pinay (Editors), Buffer Zones: Their processes and potential in water protection. Quest Environmental, pp. 265 - 274.

Cooper, A.B., Ngapo, N.I., Parminter, T.G. and Stround, M.J., 1997. Encouraging the introduction of riparian buffer zones - The New Zealand experience. In: N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Pinay (Editors), Buffer Zones: Their processes and potential in water protection. Quest Environmental, pp. 295 - 304.

Cooper, J.R., Gilliam, J.W., Daniels, R.B. and Robage, W.P., 1987. Riparian areas as filters for agricultural sediment. Soil Science Society of America, 51: 416 - 420.

Correll, D.L., 1997. Buffer zones and water quality protection: general principals. In: N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Pinay (Editors).

Dallemand, J.F. and Vossen, P., 1994. Agrometeorological models: Theory and applications in the MARS project, Institute for Remote Sensing Applications. European Commission Joint Research Centre.

DEFRA, 2002. The Government's Strategic Review of diffuse water pollution from agriculture in England: Measuring the Success of Policies to Control Diffuse Water Pollution from Agriculture, DEFRA.

DEFRA, 2004. Impacts of CAP reform agreement on diffuse water pollution from agriculture. GRP-P-175.

Dillaha, T.A. and Inamdar, S.P., 1997. Buffer zones as sediment traps or sources. In: N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Pinay (Editors), Buffer Zones: Their processes and potential in water protection. Quest Environmental, pp. 33 - 42.

Ducros, C. and Watson, N.M., 2002. Integrated Land and Water Management in the United Kingdom: Narrowing the Implementation Gap. Journal of Environmental Planning and Management, 45(3): 403-423.

Eckerberg, K. and Forsberg, B., 1996. Policy strategies to reduce nutrient leaching from agriculture and forestry and their local implementation: A case study of Laholm Bay, Sweden. Journal of Environmental Planning and Management, 39(2): 223-242.

European Commission, 1999. Agriculture and Environment, European Commission.

Foody, G.M., 2000. Estimation of sub-pixel land cover composition in the presence of untrained classes. Computers and Geosciences, 26: 469-478.

Foody, G.M., 2002. Status of land cover classification accuracy assessment. Remote Sensing of Environment, 80: 185-201.

Friedl, M.A. and Brodley, C.E., 1997. Decision Tree Classification of Land Cover from Remotely Sensed Data. Remote Sensing of Environment(61): 399-409.

Frost, A., Stewart, S., Kerr, D. and MacDonald, J., 2002. The impacts of agricultural environmental management: case studies from theory to practice. SEPA Technical Report: DPI 006, SEPA.

Geary, P.M. and Moore, J.A., 1999. Suitability of a treatment wetland for dairy wastewaters. Water Science & Technology, 40(3): 179-185.

Gilliam, J.W., Parsons, J.E. and Mikkelsen, R.L., 1997. Nitrogen dynamics and buffer zones. In: N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Pinay (Editors), Buffer Zones: Their processes and potential in water protection. Quest Environmental, pp. 54 - 61.

Haack, B. and English, R., 1996. National Land Cover Mapping by Remote Sensing. World Development, 24(5): 845-855.

Haboudane, D., Miller, J.R., Tremblay, N., Zarco-Tejada, P.J. and Dextraze, L., 2002. Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application to precision agriculture. Remote Sensing of Environment, 81: 416-426.

Hagerstrand, T., 1967. Innovation Diffusion as a Spatial Process. University of Chicago Press, Chicago.

Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (Editors), 1997. Buffer Zones: Their Processes and Potential in Water Protection. Quest Environmental, Harpenden.

Hill, R.A., Smith, G.M., Fuller, R.M. and Veitch, N., 2001. Deriving a landscape model for integrated airborne CASI and ALTM data, Remote Sensing & Photogrammetry Society - First annual meeting.

House of Lords, 1989. Nitrate in Water: Sixteenth Report from the European Communities Committee. HMSO, London.

Hudson, R., 1999. Putting Policy into Practice: Policy Implementation Problems. In: P. Balbanis, D. Peter, A. Ghazi and Tsogas (Editors), Mediterranean Desertification: Research results and policy implications. European Commission Directorate General Research, pp. 243 - 255.

Ingersoll, T.L. and Baker, L.A., 1998. Nitrate removal in wetland microcosms. Water Resources, 32(3): 677 - 684.

Institute of Hydrology, 1996. The water quality of the Tweed and its tributaries. Report no.128.

Irvine, J., 2005a. Guidance on the rules for Land Management Contracts available in the next few weeks" says Scottish Executive. www.land-care.org.uk.

Irvine, J., 2005b. SEERAD fails to show at CAP reform seminar. www.land-care.org.uk.

Jarvie, H.P. et al., 2002. Modelling nitrogen dynamics and distribution in the River Tweed, Scotland: an application of the INCA model. Hydrology and Earth System Sciences, 6(3): 433-453.

Jiggins, J., 2002. Managing change in water conservation through multi-stakeholder learning processes, An Interdisciplinary dialogue: Agriculture and Ecosystems Management.

Johnes, P.J., 1996. Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to ground waters: the export coefficient modelling approach. Journal of hydrology, 183: 323 -349.

Johnes, P.J. and Burt, T.P., 1993. Nitrate in surface waters. In: T.P. Burt, A.L. Heathwaite and S.T. Trudgill (Editors), Nitrate: Processes, Patterns and Management,. Wiley, pp. 269-317.

Johnes, P.J. and Heathwaite, A.L., 1997. Modelling the impact of land use change on water quality in agricultural catchments. Hydrological processes, 11(3): 269 - 286.

Johnson, N., Ravnborg, H.M., Westerman, O. and Probst, K., 2001. User participation in watershed management and research. Water Policy, 3: 507-520.

Koskiaho, J., Ekholm, P., Raty, M., Riihimaki, J. and Puustinen, M., 2003. Retaining agricultural nutrients in constructed wetlands -experiences under boreal conditions. Ecological Engineering, 20: 89-103.

Landcare, 2003. Landcare Australia Limited. Annual Report 2002/2003. Annual Report 2002/2003, http://www.landcareaustralia.com.au/admin.

Lilliesand, T.M. and Keifer, R.W., 2000. Remote Sensing & Image Interpretation. Wiley.

Logsdon, M.G., Bell, E.J. and Westerlund, F.V., 1996. Probability mapping of land use change: A GIS interface for visualizing transition probabilities. Computer, Environment and Urban Systems, 20(6): 389-398.

Lord, E.I., Johnson, P.A. and Archer, J.R., 1999. Nitrate Sensitive Areas: a study of large scale control of nitrate loss in England. Soil Use and Management, 15: 201 - 207.

Lowe, P., Clark, J., Seymour, S. and Ward, N., 1997. Moralizing the environment: countryside change, farming and pollution. UCL Press.

Lowrance, R., 1997. The potential role of riparian forests as buffer zones. In: N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Pinay (Editors), Buffer Zones: Their processes and potential in water protection. Quest Environmental, pp. 128 - 133.

Mather, P.M., 1999. Computer Processing of Remotely-Sensed Images. Wiley, 292 pp.

McGechan, M.B. and Wu, L., 2001. A review of carbon and nitrogen processes in European soil nitrogen dynamic models. In: M.J. Shaffer, L. Ma and S. Hansen (Editors), Modelling Carbon and Nitrogen Dynamics for Soil Management. Lewis, pp. 103 - 171.

Narumalani, S., Zhou, Y. and Jensen, J.R., 1997. Application of remote sensing and geographic information systems to the delineation and analysis of riparian buffer zones. Aquatic Botany(58): 393-409.

Norse, D., 2003. Fertilisers and world food demand. Implications for environmental stress, IFA-FAO Agriculture Conference, Rome.

O'Riordan, T. and Bentham, G., 1993. The Politics of Nitrate in the UK. In: T.P. Burt, A.L. Heathwaite and S.T. Trudgill (Editors), Nitrate: Processes, Patterns & Management. Wiley.

Osborn, S. and Cook, H.F., 1997. Nitrate Vulnerable Zones and Nitrate Sensitive Areas: A policy and technical analysis of groundwater source protection in England and Wales. Journal of Environmental Planning and Management, 40(2): 217 - 233.

Pal, M. and Mather, P.M., 2001. Decision Tree classifiers and land use classification, Remote Sensing & Photogrammetry Society - First annual meeting.

Parkinson, R.J., 1993. Changes in Agricultural Practice. In: T.P. Burt, A.L. Heathwaite and S.T. Trudgill (Editors), Nitrate: Processes, Patterns and Management. Wiley.

Platzer, C., 1999. Design recommendations for subsurface flow constructed wetlands for nitrification and denitrification. Water Science & Technology, 40(3): 257-263.

Poiret, M., 1999. Specialised holdings and more intensive practices. Eurostat (European Commission).

Power, J.F., Wiese, R. and Flowerday, D., 2001. Managing Farming Systems for Nitrate Control: A research review from Management Systems Evaluation Areas. Journal of Environmental Quality(30): 1886-1880.

Pretty, J.N., 1996. Participatory learning for integrated farming. International Institute for Environment and Development.

Race, D., Buchy, M. and Fulton, A., 2001. A dynamic context: Farm and forestry extension in Australia. International Union of Forestry Research Organizations.

Ribaudo, M., 2001. Non-point Source Pollution Control Policy in the USA. In: J.S. Shortle and D.G. Abler (Editors), Environmental Policies for Agricultural Pollution Control. CAB International.

Richards, J.A. and Jia, X., 1999. Remote Sensing Digital Image Analysis. Springer, 363 pp.

Riddell-Black, D., Alker, G., Mainstone, C.P., Smith, S.R. and Butler, D., 1997. Economically viable buffer zones - The case for short rotation forest plantations. In: N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Pinay (Editors), Buffer Zones: Their processes and potential in water protection. Quest Environmental, pp. 228 - 235.

Rogan, J. and Chen, D.M., 2004. Remote sensing technology for mapping and monitoring land-cover and land-use change. Progress in Planning, 61: 301-325.

Royal Society, 1983. The Nitrogen cycle of the United Kingdom, Royal Society, London.

Sabins, F.F., 1997. Remote sensing: principles and interpretation. W.H. Freeman, New York.

Scottish Executive, 2005. Land Management Contract deadline extended. Scottish Executive.

SEERAD, 2003a. CAP Reform: Opportunities for Scotland. Consultation Paper, http://www.scotland.gov.uk/consultations/agriculture/refo-00.asp.

SEERAD, 2003b. Guidelines for farmers in nitrate vulnerable zones. Scottish Executive, Edinburgh.

SEERAD, 2003c. Land Management Contracts: Modelling Exercise, http://www.scotland.gov.uk/library5/development/lmcme.pdf.

SEERAD, 2003d. The Rural Stewardship Scheme. http://www.scotland.gov.uk/library5/environment/rss1-00.asp, Edinburgh, pp. 133.

SEERAD, 2005a. LAND MANAGEMENT CONTRACT MENU SCHEME. www.scotland.gov.uk.

SEERAD, 2005b. Land Management Contracts Menu Scheme, Scottish Executive, Edinburgh.

SEPA, 2002a. The Future for Scotland's Waters. Guiding Principals on the Technical Requirements of the Water Framework Directive, Scottish Environmental Protection Agency.

SEPA, 2002b. Habitat Enhancement Initiative: Enhancing Sustainable Urban Drainage Systems (SUDS) for Wildlife. http://www.sepa.org.uk/publications/leaflets/suds/hei.pdf.

Serra, T., Fernando, H.J.S. and Rodriguez, R.V., 2004. Effects of emergent vegetation on lateral diffusion in wetlands. Water Research, 38: 139-147.

Shutes, R.B.E., 2001. Artificial wetlands and water quality improvement. Environment International, 26: 441-447.

Silvan, N., Vasander, H., Karsisto, M. and Laine, J., 2003. Microbial immobilisation of added nitrogen and phosphorus in constructed wetland buffers. Applied Soil Ecology, 24: 143-149.

Skop, E. and Sorensen, P.B., 1998. GIS Based modelling of solute fluxes at the catchment scale: a case study of the agricultural contribution to the riverine nitrogen loading in the Vejle Fjord catchment, Denmark. Ecological Modelling(106): 291 - 310.

Song, C., Woodcock, C.E., Seto, K.C., Lenney, M.P. and Macomber, S.A., 2001. Classification and Change Detection Using Landsat TM Data: When and How to Correct Atmospheric Effects? Remote Sensing of Environment, 75: 230-244.

Sutherland, M. and Scarsbrick, B., 2001. Landcare in Australia. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (Editors), Sustaining the global farm., pp. 160-164.

Thomson, A.G., Fuller, R.M. and Eastwood, J.A., 1998. Supervised versus unsupervised methods for classification of coasts and river corridors from airborne remote sensing. Int J. of Remote Sensing, 19(17): 3423-3431.

Tweed Forum, 2003. Tweed Catchment Management Plan: CONSULTATIVE DRAFT, Tweed Forum.

Tytherleigh, A., 1997. The establishment of buffer zones - The Habitat Scheme Water Fringe Option, UK. In: N.E. Haycock, T.P. Burt, K.W.T. Goulding and G. Pinay (Editors), Buffer Zones: Their processes and potential in water protection. Quest Environmental, pp. 255 - 264.

United States Geological Survey, 2000. Nitrogen in the Mississippi Basin - Estimating Sources and Predicting Flux to the Gulf of Mexico, USGS Factsheet No. 135-00. USGS, USA.

Vanclay, 1992. Barriers to adoption: a general overview of the issues. Rural Society, 2(2).

Vellidis, G., Lowrance, R., Gay, P. and Hubbard, R.K., 2003. Nutrient transport in a restored riparian wetland. Journal of Environmental Quality(32): 711-726.

Wade, A.J. et al., 2002. A nitrogen model for European catchments: INCA, new model structure and equations. Hydrology and Earth System Sciences, 6(3): 559 - 582.

Watson, N., Mitchell, B. and Mulamoottil, G., 1996. Integrated Resource Management : Institutional Arrangements Regarding Nitrate Pollution in England. Journal of Environmental Planning and Management, 39(1): 45-64.

Whitehead, P.G., Johnes, P.J. and Butterfield, D., 2002. Steady state and dynamic modelling of nitrogen in the River Kennet: impacts of land use change since the 1930s. The Science of The Total Environment, 282-283: 417-434.

Whitehead, P.G., Wilson, E.J. and Butterfield, D., 1998a. A semi-distributed Integrated Nitrogen model for multiple source assessment in Catchments (INCA): Part I - model structure and process equations. Science of the Total Environment, 210 / 211: 547 - 558.

Whitehead, P.G., Wilson, E.J., Butterfield, D. and Seed, K., 1998b. A semi-distributed integrated flow and nitrogen model for multiple source assessment in catchments (INCA): Part II - application to large river basins in south Wales and Eastern England. Science of the Total Environment, 210 / 211: 559 - 583.

WHO, 2002. Water and health in Europe: A joint report from the European Environment Agency and the WHO Regional Office for Europe. WHO Regional Publications. European Series, No. 93, World Health Organisation.

Appendices

Leet Catchment Farm Survey: **Name of Farm: «farmname»** Ref. No: «refnumber»

Where a choice of answer (a,b,c…yes/no) is indicated, please circle your answer.

Section One: Farm information:				
1	Size of Farm (Ha)			
2	Type of Farm:	a) Arable	b) Livestock	c) Mixed
3	Main crops grown this year (*e.g. 50% spring wheat etc. including grass*)			
4	Livestock (*type & number*)			
5	Markets: Where are the main outlets for your produce?			
6	Quality Assurance Do you belong to a "farm quality assurance scheme"? If so, which one/s?	Yes	No	
7	Are soil analyses carried out? If so, what do you test for, and how often?	Yes	No	

Section Two: Farmer Biography	
1	Ownership a) Owner Occupier; b) Tenant; c) Part of a larger business concern; d) Other (please specify below) If c) Who is the major holder? ………………………………………………………………………………
2	Educational Background of main owner / manager a) University; b) College; c) School leaver
3	Age group of main owner / manager a) 16 – 24; b) 25 – 39; c) 40 – 54; d) 55 – 69; e) 70+
4	Gender of main owner / manager a) Male; b) Female

Section Three: Knowledge of EU policy and Agricultural Guidelines								
	Below is a short list of EU Policy and guidelines that are relevant to the agriculture industry. Please circle your answer from these choices if you a) have not heard about it b) have heard about it, but not received a copy c) have received a copy, but not read it d) have read parts of it e) have read it but would like to know more about it f) have read all of it g) have read and understand it							
1	The Nitrates in Water Directive (91/676)	a	b	c	d	e	f	g
2	The Water Framework Directive (2000/60/EC)	a	b	c	d	e	f	g
3	The Bathing Water Directive (76/160/EEC)	a	b	c	d	e	f	g
4	The Nitrate Vulnerable Zone (NVZ) proposal for Scotland	a	b	c	d	e	f	g
5	PEPFAA Code *(Prevention of Environmental Pollution from Agricultural Activity)*	a	b	c	d	e	f	g
6	PEPFAA (Nitrogen and Phosphorus supplement)	a	b	c	d	e	f	g
7	Farm Waste Management Plan	a	b	c	d	e	f	g
8	Fertiliser and Manure Plan	a	b	c	d	e	f	g
9	Rural (Countryside) Stewardship Scheme	a	b	c	d	e	f	g

10	Have you sought advice on any of the above documents? If so, from whom did you seek advice? ***(If NO go to Section Four)*** (Name of organisation/s) ....
11	If advice was sought from **more than one** organisation, which was: a) the most helpful .... b) the least helpful ....
12	In general, how would you rate the quality of advice from this/these organisations: a) very poor; b) poor; c) adequate; d) good; e) very good

Section Four: Views on farming issues			
1	To what extent do you think water quality is threatened by agricultural activity? a) not at all; b) slightly; c) moderately; d) significantly; e) extremely		
2	Should regulatory measures be taken to protect **groundwater**?	Yes	No
3	Should regulatory measures be taken to protect **surface water**?	Yes	No
Please answer the following two questions with a few sentences			
4	What do you consider to be the **most important** barriers to fully complying with EU farming regulations?		
5	Is there **any other** important issue that you would like to see discussed with the regulatory authorities?		

Section Five: Finally			
1	Would you be willing to take part in a **one-to-one** in-depth interview to discuss the issues arising from this questionnaire?	Yes	No
2	Would you be willing to take part in a **group** interview to discuss the issues arising from this questionnaire?	Yes	No
3	If yes to either of the above, please state a telephone number where you can be contacted, and a preferred month for interview.	Telephone number	Preferred month

Thank you very much for taking part in this research.

University of Durham

Department of Geography

Science
Laboratories
South Road
Durham DH1
3LE
Telephone: **0191 374 2462**
Facsimile: **0191 374 2456**
E-Mail:
p.e.widdison@durham.ac.uk

Penny Widdison
Research Postgraduate

Dear «Farmersname»

I am carrying out a research project from the Department of Geography at the University of Durham. The project focuses on the Leet Catchment, to investigate the impact of European Union policy and other guidelines on land use and water quality in agricultural areas.

I am writing to farmers in the Leet Water and Lambden Burn areas, to enable me to build up a picture of the farming community and existing land use. I am particularly interested in finding out the views of local farmers and how they see the impacts of current and forthcoming legislation on farming practices. I would be very grateful if you would take a few minutes to fill in the enclosed questionnaire and return it in the enclosed pre-paid addressed envelope.

Later in the project I will be conducting one-to-one interviews (lasting about 45 minutes) and group discussions. This will enable me to find out more detail about reactions to EU policy, and the issues relating to water quality that the farming community consider important. If you would like to take part in either, or both of these interviews to make your views known please would you indicate this on the questionnaire.

This project is being conducted with the knowledge and approval of SEPA and the Scottish Executive. However, I would like to stress that any details contained in your responses will be treated with the utmost confidentiality. Findings from the interviews will be published as part of the research but individual identities will not be disclosed to third parties without your knowledge or consent.

Yours sincerely

Penny Widdison
Research Postgraduate.

University of Durham

Department of Geography

Science Laboratories
South Road
Durham DH1 3LE
Telephone: **0191 374 1190**

E-Mail: **p.e.widdison@durham.ac.uk**

Penny Widdison
Research Postgraduate

Dear Sir,

Thank you for taking the time to complete and return the recent questionnaire on farming in the Leet catchment which is currently being undertaken from the Department of Geography at the University of Durham. You very kindly indicated you would like to take part in the one-to-one interviews. I would now like to arrange a mutually convenient time to set this up. I have indicated the times and dates I would be able to travel to the Leet catchment on the slip below. If none of these dates are suitable, I will be available again after the 20th January. I would be grateful if you would complete and return this slip in the enclosed stamped addressed envelope.

The interviews will take approximately 45 minutes, and confidentiality will be upheld. This interview is very important to the research as it will enable me to find out more detail about the impacts of EU policy, farming practices and the issues relating to water quality that the farming community consider important.

Yours faithfully

Penny Widdison

Research Postgraduate.

Name of Farm ....Ref No.......................

Contact Name .... Phone number ....

Please indicate by writing 1or 2 in the boxes to indicate which day and time are: 1 – most, and 2 - second most suitable for interview. I will then confirm the agreed meeting by telephone.

Tuesday	10th December	11.00 am		1.00 pm	
Wednesday	11th December	11.00 am		1.00 pm	
Thursday	12th December	11.00 am		1.00 pm	
Tuesday	16th December	11.00 am		1.00 pm	
Wednesday	17th December	11.00 am		1.00 pm	
Thursday	18th December	11.00 am		1.00 pm	
Tuesday	6th January	11.00 am		1.00 pm	
Wednesday	7th January	11.00 am		1.00 pm	
Thursday	8th January	11.00 am		1.00 pm	

Suitable date after 20th January ....

Farm Survey: Biographical details								
ID	SIZE_OF_FARM	TYPE_OF_FARM	QAS	OWNERSHIP	EDUCATION	AGE_GROUP	GENDER	ONE_TO_ONE_INTERVI
Leet-002	300	a	Yes	c	a	c	Male	Yes
Leet-009	162	a	Yes	a	c	b	Male	No
Leet-019	140	a	No	b	a	b	Male	Yes
Leet-026	240	a	No	a	b	c	Male	No
Leet-040	252	a	Yes	b	b	c	Male	No
Leet-046	320	a	Yes	a	b	c	Male	No
Leet-048	180	a	Yes	a	b	b	Male	Yes
Leet-058	154	a	Yes	a	b	b	Male	No
Leet-074	160	a	Yes	a	b	d	Male	No
Leet-082	813	a	Yes	a	c	d	Male	No
Leet-107	200	a	Yes	a	a	d	Male	No
Leet-001	117	c	Yes	b	b	c	Male	Yes
Leet-008	1000	c	Yes	a	b	d	Male	No
Leet-010	100	c	Yes	a	c	b	Male	Yes
Leet-012	1	c	No	a	a	d	Female	No
Leet-013	160	c	Yes	a	b	c	Male	No
Leet-014	200	c	Yes	a	c	c	Male	No
Leet-015	200	c	Yes	a	b	b	Male	Yes
Leet-017	110	c	Yes	a	b	d	Male	Yes
Leet-021	60	c	Yes	a	c	d	Male	No
Leet-023	365	c	Yes	a	b	c	Male	Yes
Leet-025	350	c	Yes	a	b	c	Male	No
Leet-027	2100	c	Yes	a	b	c	Male	Yes
Leet-031	224	c	Yes	a	b	c	Male	Yes
Leet-033	105	c	Yes	a	c	d	Male	Yes
Leet-034	221	c	Yes	a	a	d	Male	No
Leet-038	420	c	Yes	a	b	c	Male	No
Leet-041	177	c	Yes	a	c	c	Male	No
Leet-047	131	c	Yes	a	b	d	Male	No
Leet-049	1010	c	Yes	a	b	c	Male	No
Leet-069	220	c	Yes	a	a	b	Male	No
Leet-070	17	c	No	b	c	d	Male	Yes
Leet-072	312	c	Yes	a	c	c	Male	No
Leet-073	267	c	Yes	a	c	d	Male	No
Leet-075	169	c	Yes	b	c	c	Male	Yes
Leet-076	175	c	Yes	a		d	Male	Yes
Leet-091	82	c	Yes	a	c	d	Male	No
Leet-102	46	c	Yes	a	c	d	Male	No
Leet-054	0	ısed to re	No					No

Appendix 1d: Questionnaire responses: knowledge of regulations and guidelines

Knowledge of regulations									
Question:	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
ref no	NITRATES	WATER_FR	BATHING	NVZ_PROP	PEPFAA_C	PEPFAA_N	FARM_WAS	FERT_AND	RURAL_ST
Leet-001	3	1	2	3	1	1	2	1	2
Leet-002	2	2	2	7	2	2	2	2	7
Leet-008	6	2	1	6	2	1	7	5	5
Leet-009	6	1	1	7	1	1	1	6	7
Leet-010	6	2	1	5	1	1	2	2	5
Leet-012	2	1	2	1	1	1	1	1	2
Leet-013	4	1	2	7	4	4	4	4	2
Leet-014	4	1	4	6	3	3	4	4	6
Leet-015	2	1	2	3	2	1	1	2	2
Leet-017	7	7	7	7	7	1	1	1	7
Leet-019	3	1	1	7	7	1	7	2	3
Leet-021	7	1	1	7	7	7	7	7	7
Leet-023	4	1	1	4	4	2	4	4	2
Leet-025	4	1	1	4	1	1	4	4	4
Leet-026	4	1	1	3	1	1	1	1	2
Leet-027	7	6	6	7	7	6	7	7	7
Leet-031	6	1	1	6	6	6	6	6	5
Leet-033	4	4	2	6	7	7	4	4	4
Leet-034	2	2	1	4	6	1	7	4	2
Leet-038	2	1	1	6	1	1	2	2	2
Leet-040	6	1	1	6	1	1	1	1	4
Leet-041	5	1	1	5	4	5	7	7	7
Leet-046	4	1	1	4	1	1	4	4	7
Leet-047	6	6	2	6	6	4	4	4	6
Leet-048	2	1	1	6	4	2	2	1	4
Leet-049	5	5	5	7	7	6	7	7	7
Leet-058	2	1	1	6	1	1	3	2	3
Leet-069	1	1	1	4	1	1	1	1	4
Leet-070	6	1	1	2	1	1	2	6	1
Leet-072	2	1	2	6	6	2	4	2	4
Leet-073	4	1	1	5	4	1	4	2	4
Leet-074	4	4	2	4		4	6	6	7
Leet-075	2	1	1	4	4	4	2	2	6
Leet-076	4	1	2	6	2	2	4	4	4
Leet-082	4	4	4	4	2	1	2	2	5
Leet-091	4	1	1	4	4	2	5	4	5
Leet-102	4	1	1	5	4	1	1	1	3
Leet-107	1	1	1	4	7	4	4	7	7

Testing the relationship between knowledge of regulations and socio-economic factors

See Appendix 1c biographical details for group categories

Age Group

	Observed frequencies (O)							Expected Frequencies (E)							Difference between observed and expected Frequencies ((O-E)^2/E)						total Chi-sq	degrees of freedon	0.05 probability
	0-9	10-18	19-27	28-35	36-45	n		0-9	10-18	19-27	28-35	36-45	n		0-9	10-18	19-27	28-35	36-45	n			
a	0	0	0	0	0	0	a	0.00	0.00	0.00	0.00	0.00	0	a	0.00	0.00	0.00	0.00	0.00	0			
b	3	4	0	0	0	7	b	1.47	3.50	1.29	0.55	0.18	7	b	1.58	0.07	1.29	0.55	0.18	7	**8.49**	**16**	**26**
c	3	9	2	1	1	16	c	3.37	8.00	2.95	1.26	0.42	16	c	0.04	0.13	0.30	0.05	0.80	16			
d	2	6	5	2	0	15	d	3.16	7.50	2.76	1.18	0.39	15	d	0.42	0.30	1.81	0.56	0.39	15			
e	0	0	0	0	0	0	e	0.00	0.00	0.00	0.00	0.00	0	e	0.00	0.00	0.00	0.00	0.00	0			
total	***8***	***19***	***7***	***3***	***1***	***38***		***8***	***19***	***7***	***3***	***1***	***38***		***8***	***19***	***7***	***3***	***1***	***38***			

Level of education

	0-9	10-18	19-27	28-35	36-45	n		0-9	10-18	19-27	28-35	36-45	n		0-9	10-18	19-27	28-35	36-45	n	total Chi-sq	degrees of freedon	0.05 probability
a	2	3	1	0	0	6	a	1.26	3.00	1.11	0.47	0.16	6	a	0.43	0.00	0.01	0.47	0.16	6	**5.19**	**8**	**16**
b	5	7	4	2	1	19	b	4.00	9.50	3.50	1.50	0.50	19	b	0.25	0.66	0.07	0.17	0.50	19			
c	1	9	2	1	0	13	c	2.74	6.50	2.39	1.03	0.34	13	c	1.10	0.96	0.07	0.00	0.34	13			
total	***8***	***19***	***7***	***3***	***1***	***38***		***8***	***19***	***7***	***3***	***1***	***38***		***8***	***19***	***7***	***3***	***1***	***38***			

Farm Tenure

	0-9	10-18	19-27	28-35	36-45	n		0-9	10-18	19-27	28-35	36-45	n		0-9	10-18	19-27	28-35	36-45	n	total Chi-sq	degrees of freedon	0.05 probability
a	7	5	14	3	1	30	a	6.32	5.53	15.00	2.37	0.79	30	a	0.07	0.05	0.07	0.17	0.06	30	**2.77**	**8**	**16**
b	1	2	4	0		7	b	1.47	1.29	3.50	0.55	0.18	7	b	0.15	0.39	0.07	0.55	0.18	7			
c	0	0	1	0		1	c	0.21	0.18	0.50	0.08	0.03	1	c	0.21	0.18	0.50	0.08	0.03	1			
total	***8***	***7***	***19***	***3***	***1***	***38***		***8***	***7***	***19***	***3***	***1***	***38***		***8***	***7***	***19***	***3***	***1***	***38***			

Introduction:
General warm up questions will include a practical task of outlining the extent of the farm on a photocopy base map, field names, sizes, last years cropping pattern.

Remind farmer of purpose of interview:
Trying to find out about the main factors that influence decision making on farming practices in general and in particular in the light of NVZ designation and water quality regulations.

Part One: ***The Farm***
Is this a family run farm? Has it been in the family for many years? Will it remain so for the next generation – if not what might happen to farm land?

(How long has the farm been part of a larger business concern? Who is the owner?)

Has this farm always been this size? If it is a result of farm amalgamations, which other farms have been incorporated into this unit? Are there plans for further amalgamations? What do you think will happen to the farm in say 20 years time – Will it stay in the family, or remain part of the same business unit?

Part Two: ***Perceptions on the quality of river environment***
Could we talk about what you think about water quality in the immediate area.
Do you think water in the Leet and the Lambden Burn are polluted?

> If yes – what do you think are the main pollutants, where do you think these pollutants come from? Do you think there have been changes in the quality of the water in recent years?
> If no – Water quality monitoring have indicated that levels of Nitrate and Phosphate have been above the limits set by the EU. Where do you think these pollutants could come from?

Penalties for polluting water courses:
What do you know about existing penalties for being responsible for water pollution incidents?
Who are the existing regulators for pollution incidents? –
Do you meet with the regulators?
Is this always a formal or informal meeting or a mixture of both?
How would you explain your relationship with the regulators?
How do you think this relationship could be improved?
Do you think regulations should be brought in (and enforced) to reduce levels of N and P in the Leet / Lambden – explain answer?
What do you think about the government stance that the 'polluter pays'...

Part Three: ***Official Policy and guidelines***

The PEPFAA code
The PEPFAA code of good practice (Prevention of Environmental Pollution from Agricultural Activity) has been produced by the Scottish Office with assistance from SAC. What do you know about the PEPFAA code (including the N and P supplement)?
Have you received a copy?
If yes - In what way is it relevant to your day to day farming?
Has it influenced the way the make decisions?
Do you think changes need to be made to the code? If so what changes would you like to see?

The Nitrate Vulnerable Zone designation

Could we talk about the recent designation creating a Nitrate Vulnerable Zone in this area. The postal survey indicated that most farmers in the catchment received a copy of the NVZ proposal. Did you respond to the NVZ proposal consultation document? If yes, may I ask what you said? If no, may I ask why you didn't.

How do you feel about the NVZ designation?

What do you know about the NVZ proposal for Lothian and Borders?
How do you think the designation will affect this particular farm?

How do you think the designation will affect other farms in the area *(can you name areas)* ?

Do you think there are farms in the area that set a good example for protecting the quality of water?
How do you think this affects other farms in the area? Do they act a 'lead' – encourage more good practice amongst other farms?
Are there farms that seem to flaunt the regulations – do they 'get away with it' – how does this affect other farms in the area?

Water Quality guidelines

One of the questions on the postal survey asked about the EU Water Framework Directive, over 70% of the farmers in this area had not heard of it.

How do you think information from documents such as this should be passed on to the farming community?

The Water Framework Directive talks about 'Integrated Catchment Management'
What do you think the term 'Integrated catchment management' means? *(bringing together representatives from relevant groups of interested parties within a river catchment area eg fishing, farming, forestry, wildlife, environment, conservation, water companies to discuss management ideas and strategies that will benefit all groups rather than just them selves)*

Do you think Integrated Catchment Management is a good idea?

Should involvement in ICM schemes and in particular the farming community be Compulsory / Voluntary?
Do you think there should be some form of benefit to the farmers that belong to such schemes?
If no, why not?
If yes, what should that benefit be?

Do you think regulations and guidelines for protect water quality are clearly set out?
Do you think there is sufficient guidance on how the regulations should be interpreted?
Are there any regulations that you feel are more relevant to / less relevant to the borders of Scotland?

Do you know of any other water quality regulation that may affect farming in this area?

Do you think it is important for the EU to be setting out legislation for the protection of water quality?

Part Four: ***Factors affecting decision making***

Could we now focus on particular factors that you take into consideration when making decisions about your farming practices.

What would you say are the three most important factors that you take into account when you are:
a) deciding what crops to sow and / or stock to keep for the next year?
b) Deciding what type of fertiliser you are going to use (inorganic/ organic)
c) Deciding when (date) to apply fertilisers
d) Deciding how much (quantity) fertiliser to apply

During my research I have come across a great number of regulations. May I ask how do you manage to keep up with legislation and regulations?

Do you read every document sent to you?
How do you decide which documents to read thoroughly / partly / ignore?

What do you do if there are parts of the codes/guidelines you feel you can't comply with – do you discuss this some of the advisory agencies / complain to regulators.

How much of the codes do you manage to comply with – is this every year, or are some years better / worse than others?
Are there specific areas of legislation / regulation that you feel you an unable to comply with? *(Examples / explain answer)*

To what extent do you think the existing regulations have influenced the way you make your decisions about day to day farming?

How do you think the government should encourage farmers to fully comply with regulations?

Part Five: ***Fertiliser practices***
Could we talk a little in detail of your fertiliser practices.

Do you keep a record of your Fertiliser use? – What fertiliser do you use? organic / inorganic fertilisers? *(About how much money do you spend on fertiliser a year?)*
How do you decide how much fertiliser (of both types) to use on each field? *(Do you have a copy of MAFF booklet RB209 – Fertiliser recommendations for Agricultural and Horticultural crops?)*
Does this vary from field to field / year to year? – How has your fertiliser application changed in the last 10 years or 20 years? – Are you using more / less/ different mix of inorganic / organic?

How do you decide when is the best time to apply fertilisers?
How do you decide the quantity and type of fertiliser to apply each time?

What do you know about the regulations that restrict timing and amount of fertiliser application?
Do you think you are able to fully comply with this regulation?
Have there been instances when you broken the rules and applied fertiliser? – What made you do this? *(Did you get 'caught'? What happened?)* Would you break the rules again?
Would you let us see your fertiliser plan (records for last 5 years) ?

Part Six: ***Environmental Farming Practices***
Are you aware of the terms 'good agricultural practice' and 'agri-environment' – What do these terms mean to you?

Have you made any 'agri-environment' changes to your farming practices that go beyond 'good agricultural practice'? – e.g. (buffer strips to fields adjacent to water courses)

How have these affected your farm in terms of economics benefits / losses?
How have these affected your farm in terms of environmental benefits/losses?
How have these affected the day to day running of your farm?

Would you consider making more (or introducing) 'agri-environment improvements' to your farm? If yes – what? If no – could you explain why?

Do you know of any grants or funds that are available for introducing agri-environment improvements?

If yes - Have you applied for grants? If no what prevented you from doing this?
If yes, could you talk me through the process, were you successful?

Would you recommend applying for funds to other farmers in the area?

Would you consider reducing the amount of inorganic fertiliser to your land?
What affect do you think this would have on farm output?

Some respondents to the survey said they approached SAC (Scottish Agricultural College) or SEPA for advice, do you know of any other agencies that could offer advice on agricultural guidelines?

Finally **- Farming, the countryside and the general public**

In recent years farmers and farming issues have been in the news quite often,
Do you think the general public's perception of farming affects your day to day management?
If yes how,
if no why not?
Do you think farmers have 'a duty' to protect the countryside? - Could you give reasons for your answer?

Thank you for sharing your views on the issues raised from the questionnaire. Are there any other points that we have not talked about that you think are important to the issue of water quality in agricultural catchments?

Four CDs containing eight files of image data and AZEXHDF software received January 2003:

A194011B.HDF;	A194021B.HDF;	A194031B.HDF;	A194041B.HDF;
A194051B.HDF;	A194061B.HDF;	A194071B.HDF;	A194081B.HDF;

RS data is described as being of a certain level, describing the amount of processing which has occurred since data collection. This works on an internationally recognised scale, defined by NASA.

Level	Characteristics
0	Raw 'sensor format' data at original resolution
1a	Level 0 – reformatted to image files with ancillary files appended
1b	Level 1a with radiometric calibration to produce radiance or irradiance; and, locational and navigational information appended
2	Geophysical or environmental parameters (may include atmospheric correction) derived from Level 1a or 1b data
3a	Level 1b or 2 data mapped to a geographic co-ordinate system using on-board attitude and positional information only
3b	Level 1b or 2 data mapped to a geographic co-ordinate system using on-board attitude and positional information with additional ground control points
4	Multi-temporal / multi-sensor gridded data products

Source: http://www.neodc.rl.ac.uk/tutorials/nercarsf/2.htm

The AZEXHDF software enables ARSF ATM data, provided in Hierarchical Data Format, to be read into any processing system in a flat file format.

Customised AZGCORR software downloaded from the ARSF FTP site. This enables the user to geometrically rectify (to level 3a) the ATM data, to British National Grid projection or to a user defined map projection.

Note on file names:

A194011B.HDF

A	=	ATM data;
194	=	the Julian day of flight; (13th July)
01	=	flight line number;
1B	=	level of radiometric calibration.
.HDF	=	data format – Hierarchal Data Format

During initial data extraction, names were shortened and changed to lower case for compatibility with UNIX system and ease to use. For example, ***A194011B.hdf*** *named* ***atm-01*** *in output.*

Using AZGCORR software (automated geometric correction of ATM data).

run AZGCORR software:

% azgcorr –1 a194011b.hdf –3 atm01_gc –p 5 5

where:

azgcorr	software to be used
-1	input level of data
a194011b.hdf	name of input file
-3	output level of geocorrection
atm01_gc.hdf	name of output file
-p 5 5	output pixel size (NERC recommend no smaller than 5x5m)

Extracting processing information from files:

Command line:

% azexhdf atm01_gc.hdf –r –B atm-01

where:

azexhdf	is the name of software;
atm01_gc.hdf	is the name of input file:
-r	is request to extract radiance data
-B	is request to extract Band interleaved file BIL data
atm-01	is name of output file

Extracting header data from files:

Command line:

% azexhdf –h atm01.hdf header_01.txt>header_01.txt

Where:

header information (-h) is extracted and sent to a text file (header_01.txt)

This can be opened in notepad for printing. Using >header_01.txt stops a screen version appearing. (useful as header is four pages of text).

Image files are then ready for use in generic software packages such as ENVI or ERDAS IMAGINE.

```
ENVI Decision Tree Text File (version=1.0)

begin node
  name = "b5 < 1100"
  type = Decision
  location = 1,1
  expression = "(b5 lt 1100)"
end node

begin node
  name = "Discard"
  type = Result
  location = 2,2
  parent name = "b5 < 1100"
  parent decision = Yes
  class value = 1
  class rgb = 255,255,255
end node

begin node
  name = "b5 < 1300"
  type = Decision
  location = 2,1
  parent name = "b5 < 1100"
  parent decision = No
  expression = "(b5 lt 1300)"
end node

begin node
  name = "P. Pasture"
  type = Result
  location = 3,2
  parent name = "b5 < 1300"
  parent decision = Yes
  class value = 3
  class rgb = 0,255,0
end node

begin node
  name = "b5 < 2000"
  type = Decision
  location = 3,1
  parent name = "b5 < 1300"
  parent decision = No
  expression = "(b5 lt 2000)"
end node

begin node
  name = "discard"
```

```
 type = Result
 location = 4,2
 parent name = "b5 < 2000"
 parent decision = Yes
 class value = 4
 class rgb = 255,255,255
end node

begin node
 name = "b5 < 2400"
 type = Decision
 location = 4,1
 parent name = "b5 < 2000"
 parent decision = No
 expression = "(b5 lt 2400)"
end node

begin node
 name = "Sp. OSR"
 type = Result
 location = 5,2
 parent name = "b5 < 2400"
 parent decision = Yes
 class value = 5
 class rgb = 255,255,0
end node

begin node
 name = "b5 < 3300"
 type = Decision
 location = 5,1
 parent name = "b5 < 2400"
 parent decision = No
 expression = "(b5 lt 3300)"
end node

begin node
 name = "W.Barley"
 type = Result
 location = 6,2
 parent name = "b5 < 3300"
 parent decision = Yes
 class value = 8
 class rgb = 0,0,255
end node

begin node
 name = "b7 < 0"
 type = Decision
 location = 6,1
```

```
  parent name = "b5 < 3300"
  parent decision = No
  expression = "(b7 lt 0)"
end node

begin node
  name = "Discard"
  type = Result
  location = 7,2
  parent name = "b7 < 0"
  parent decision = Yes
  class value = 9
  class rgb = 255,255,255
end node

begin node
  name = "b7 < 700"
  type = Decision
  location = 7,1
  parent name = "b7 < 0"
  parent decision = No
  expression = "(b7 lt 700)"
end node

begin node
  name = "Water"
  type = Result
  location = 8,2
  parent name = "b7 < 700"
  parent decision = Yes
  class value = 10
  class rgb = 255,0,255
end node

begin node
  name = "b7 < 2300"
  type = Decision
  location = 8,1
  parent name = "b7 < 700"
  parent decision = No
  expression = "(b7 lt 2300)"
end node

begin node
  name = "Buildings"
  type = Result
  location = 9,2
  parent name = "b7 < 2300"
  parent decision = Yes
  class value = 11
```

```
 class rgb = 176,48,96
end node

begin node
 name = "b7 < 3000"
 type = Decision
 location = 9,1
 parent name = "b7 < 2300"
 parent decision = No
 expression = "(b7 lt 3000)"
end node

begin node
 name = "Stubble"
 type = Result
 location = 10,2
 parent name = "b7 < 3000"
 parent decision = Yes
 class value = 12
 class rgb = 46,139,87
end node

begin node
 name = "b7 > 3500 & < 4000"
 type = Decision
 location = 10,1
 parent name = "b7 < 3000"
 parent decision = No
 expression = "(b7 gt 3500) and (b7 lt 4000)"
end node

begin node
 name = "Woodland/conifers"
 type = Result
 location = 11,2
 parent name = "b7 > 3500 & < 4000"
 parent decision = Yes
 class value = 13
 class rgb = 160,32,240
end node

begin node
 name = "b7 > 5500, < 5700"
 type = Decision
 location = 11,1
 parent name = "b7 > 3500 & < 4000"
 parent decision = No
 expression = "(b7 gt 5500) and (b7 lt 5700)"
end node
```

```
begin node
 name = "W.Wheat"
 type = Result
 location = 12,2
 parent name = "b7 > 5500, < 5700"
 parent decision = Yes
 class value = 14
 class rgb = 255,127,80
end node

begin node
 name = "b7 >6500, < 6800"
 type = Decision
 location = 12,1
 parent name = "b7 > 5500, < 5700"
 parent decision = No
 expression = "(b7 gt 6500) and (b7 lt 6800)"
end node

begin node
 name = "W.OSR"
 type = Result
 location = 13,2
 parent name = "b7 >6500, < 6800"
 parent decision = Yes
 class value = 15
 class rgb = 127,255,212
end node

begin node
 name = "b7 >7000, < 7800"
 type = Decision
 location = 13,1
 parent name = "b7 >6500, < 6800"
 parent decision = No
 expression = "(b7 gt 7000) and (b7 lt 7800)"
end node

begin node
 name = "Sp Oats"
 type = Result
 location = 14,2
 parent name = "b7 >7000, < 7800"
 parent decision = Yes
 class value = 16
 class rgb = 218,112,214
end node

begin node
 name = "Class 2"
```

```
 type = Result
 location = 14,1
 parent name = "b7 >7000, < 7800"
 parent decision = No
 class value = 2
 class rgb = 0,255,255
end node

begin variable
 variable name = "b5"
 file name = "C:\ENVI-files\1234-mosaic"
 file pos = 5
end variable

begin variable
 variable name = "b7"
 file name = "C:\ENVI-files\1234-mosaic"
 file pos = 7
end variable
```

Figure 6.1c NO3-N concentrations October 2002

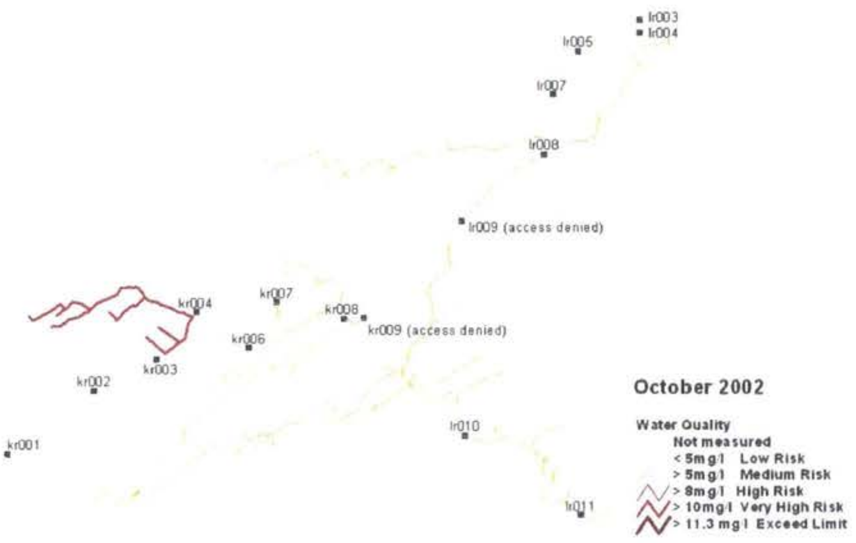


Figure 6.1d NO_3-N concentrations November 2002

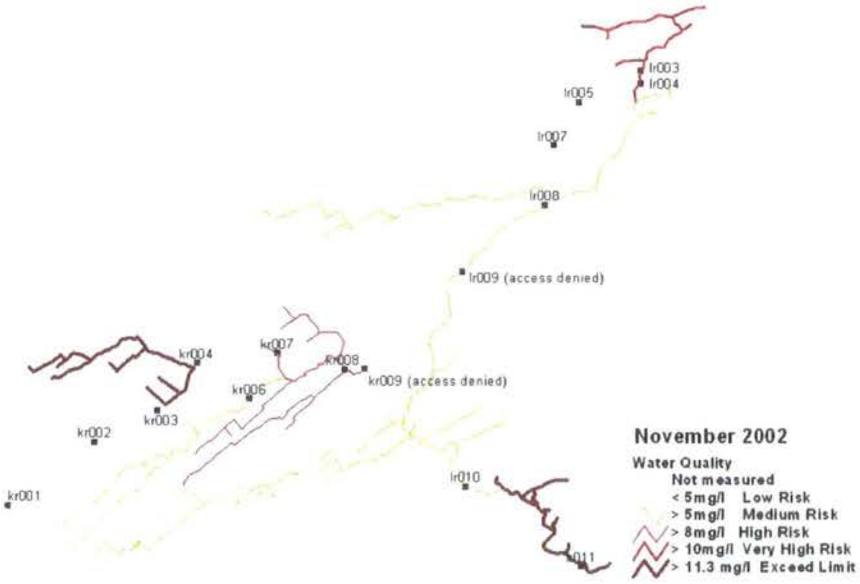


Figure 6.1e NO_3-N concentrations December 2002

Figure 6.1f NO_3-N concentrations January 2003

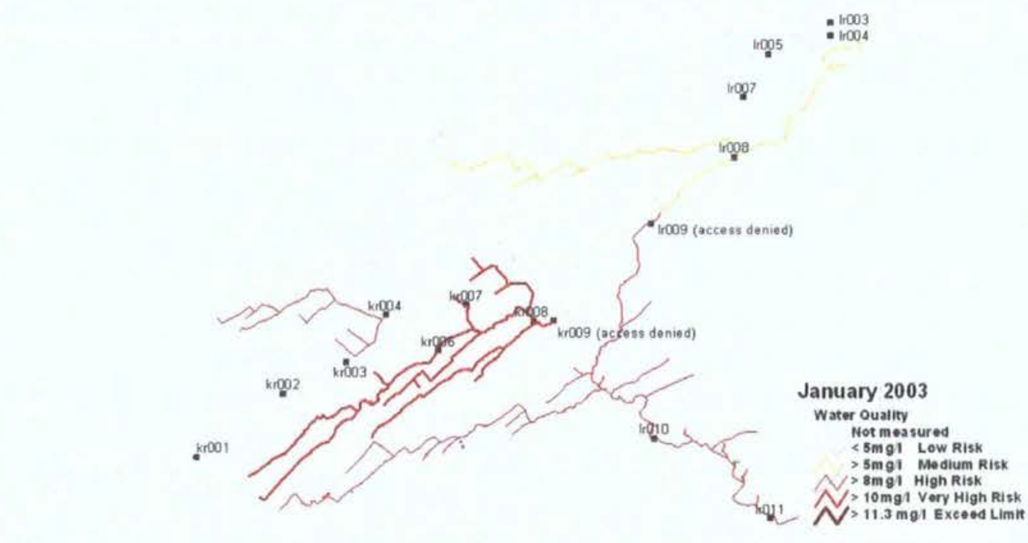


Figure 6.1g NO$_3$-N concentrations February 2003

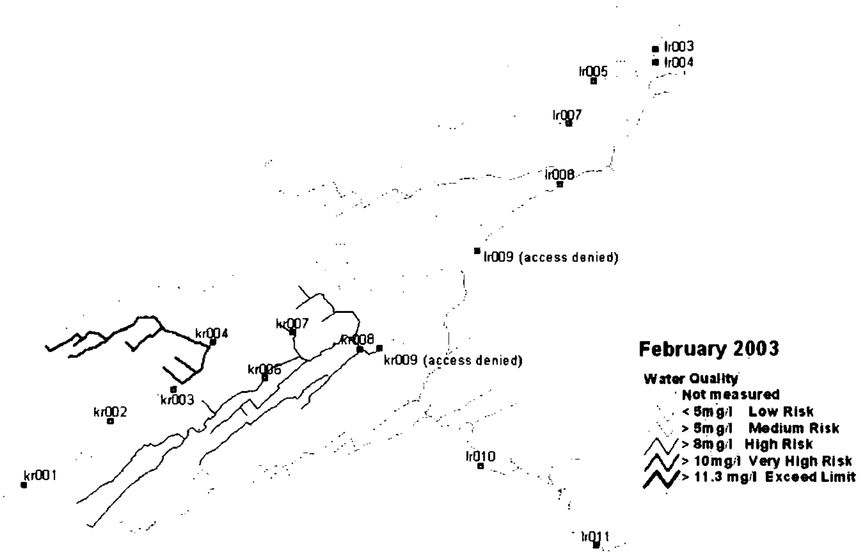


Figure 6.1h NO$_3$-N concentrations March 2003

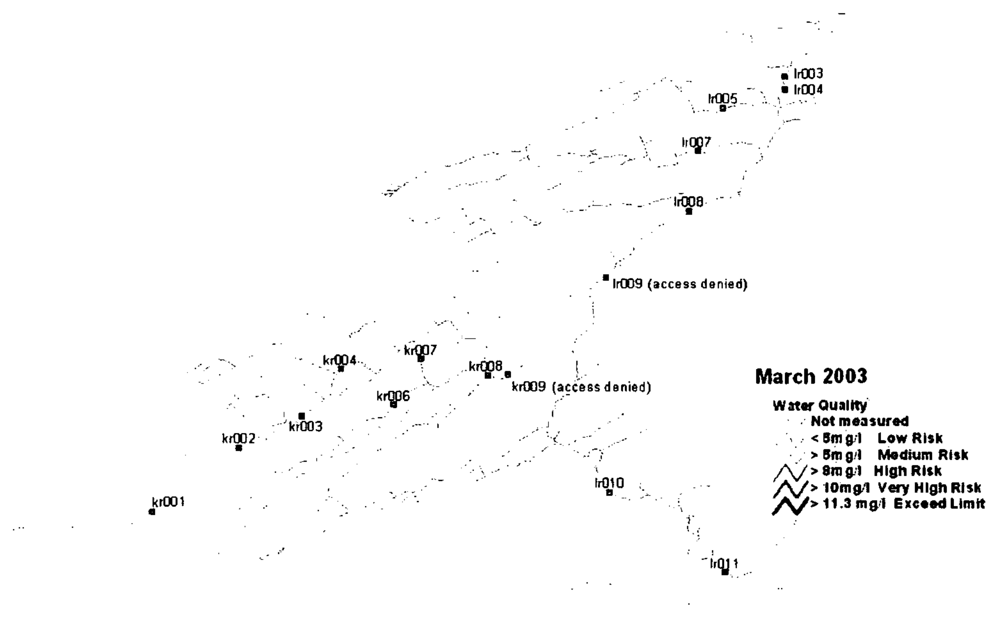


Figure 6.1i NO_3-N concentrations April 2003

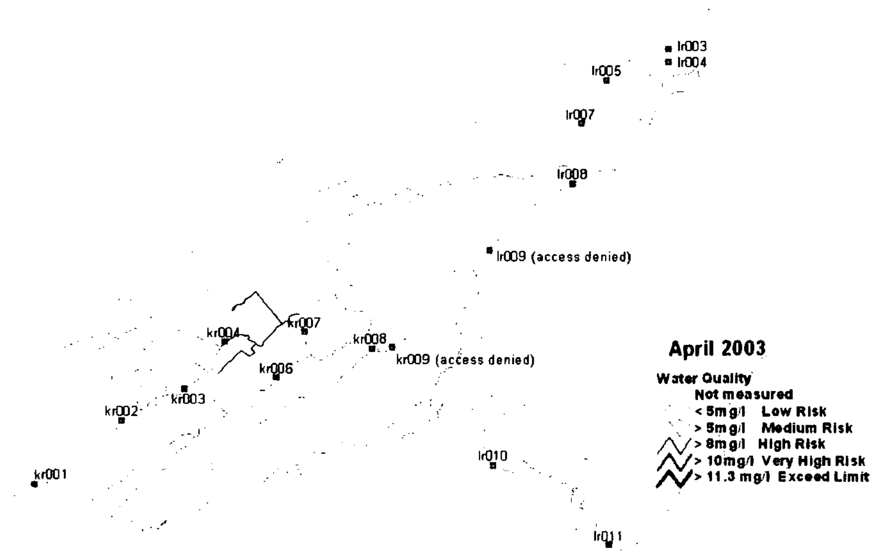


Figure 6.1j NO_3-N concentrations May 2003

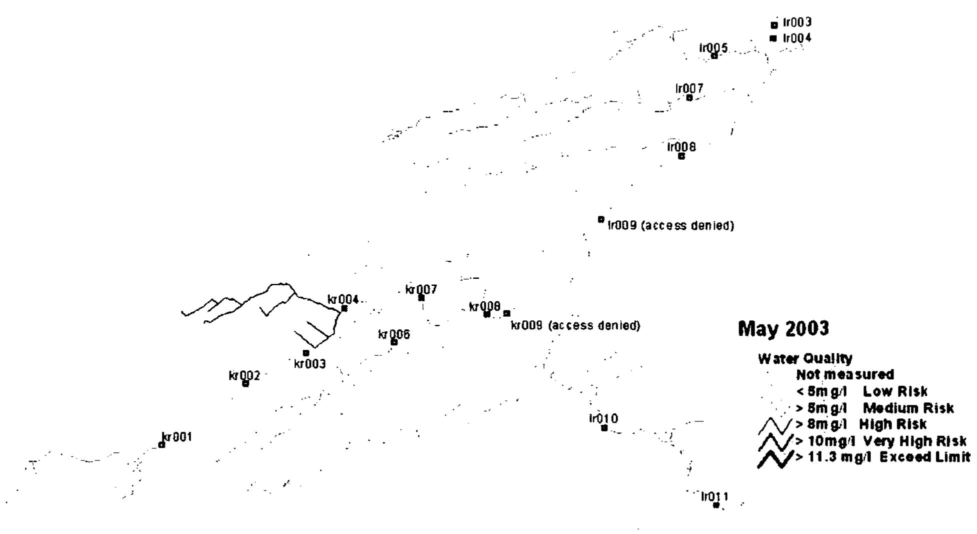


Figure 6.1k NO_3-N concentrations June 2003

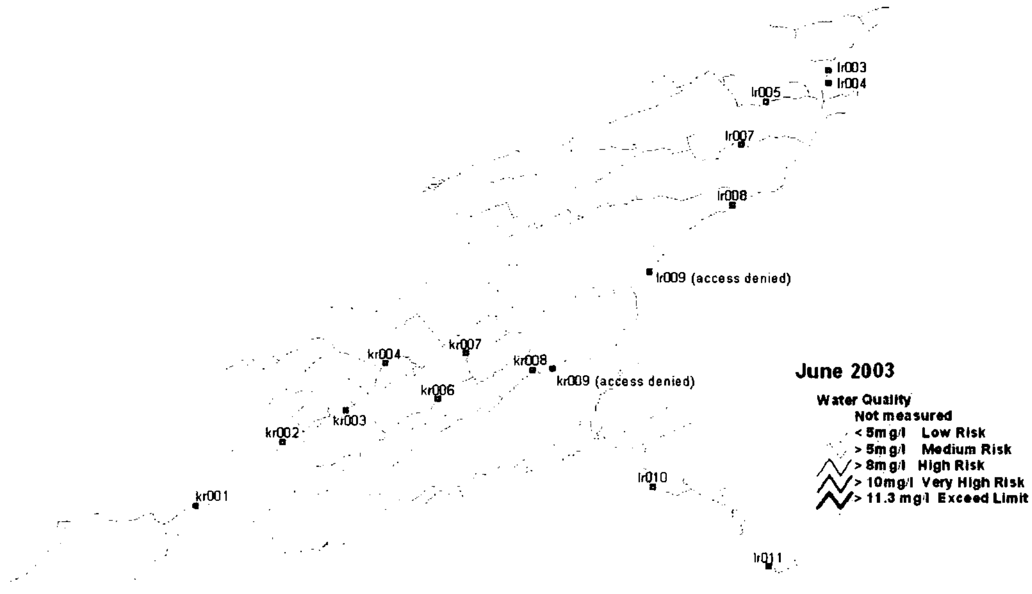


Figure 6.1l NO_3-N concentrations August 2003

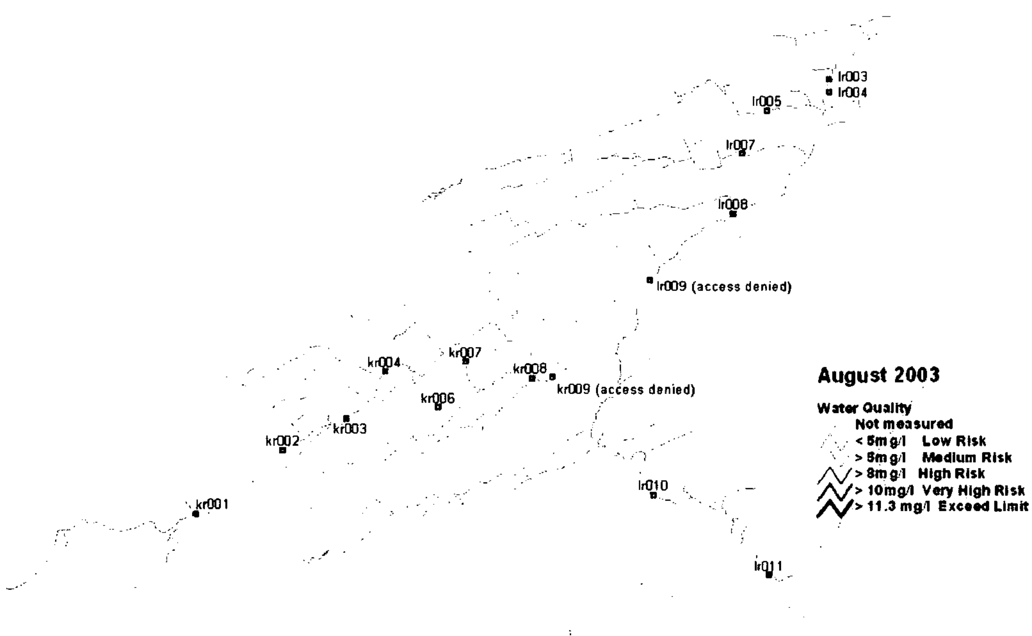


Figure 6.1m NO$_3$-N concentrations September 2003

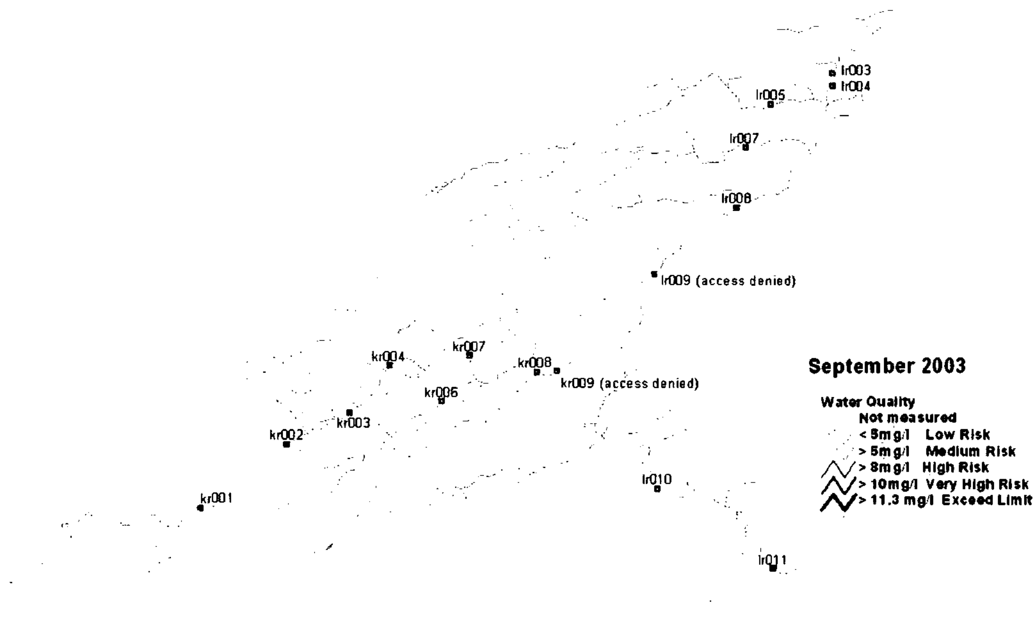


Figure 6.1n NO$_3$-N concentrations October 2003

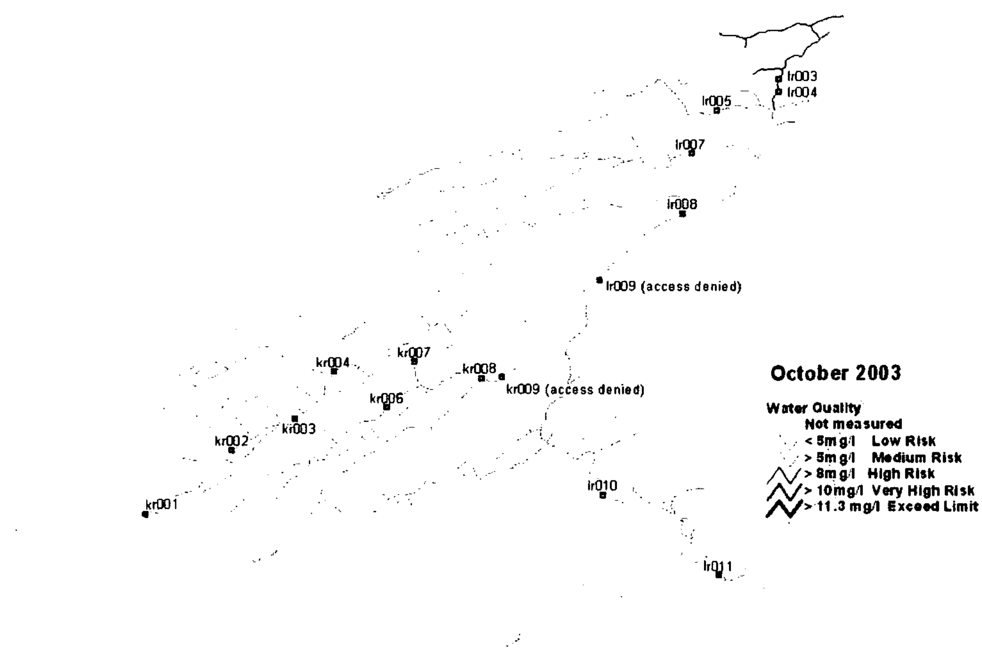


Figure 6.1o NO_3-N concentrations November 2003

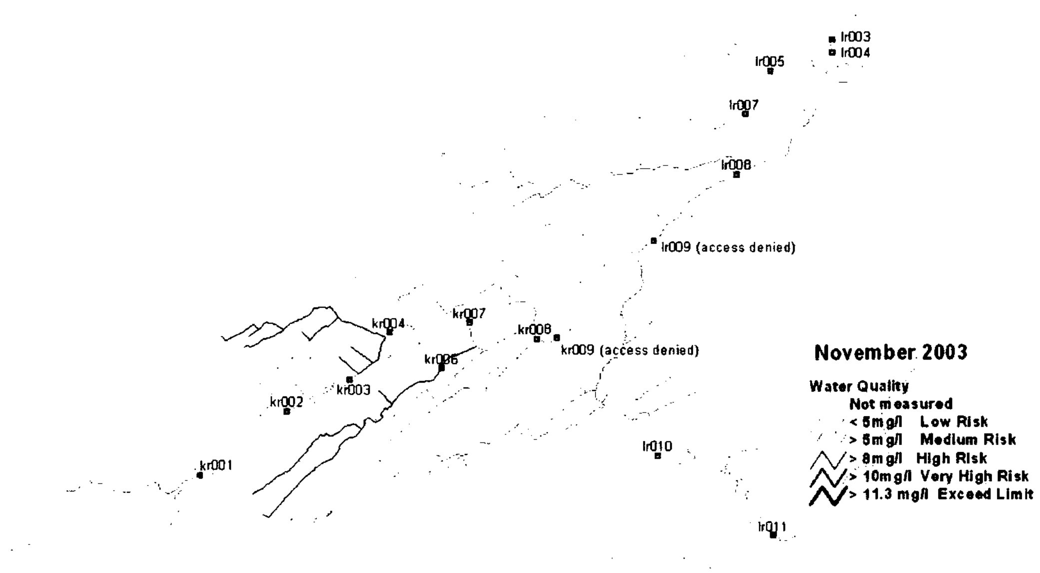


Figure 6.1p NO_3-N concentrations December 2003

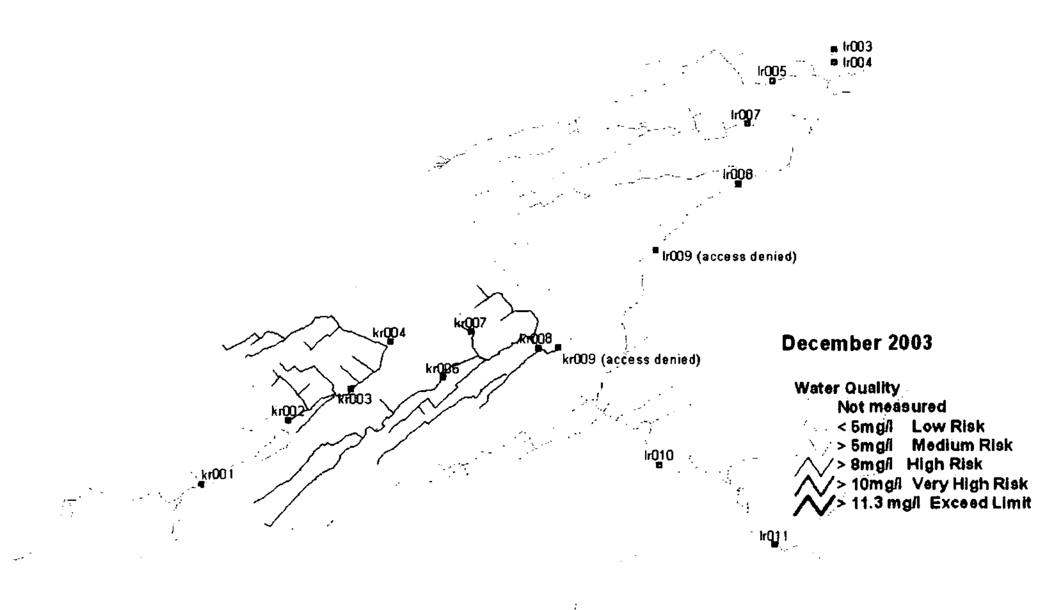


Figure 6.1q NO_3-N concentrations March 2004

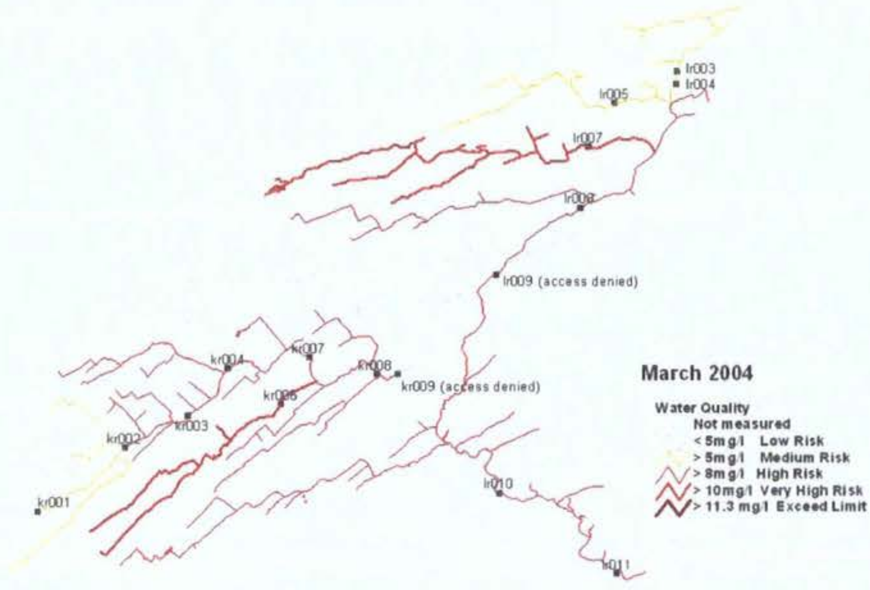


Figure 6.1r NO_3-N concentrations April 2004

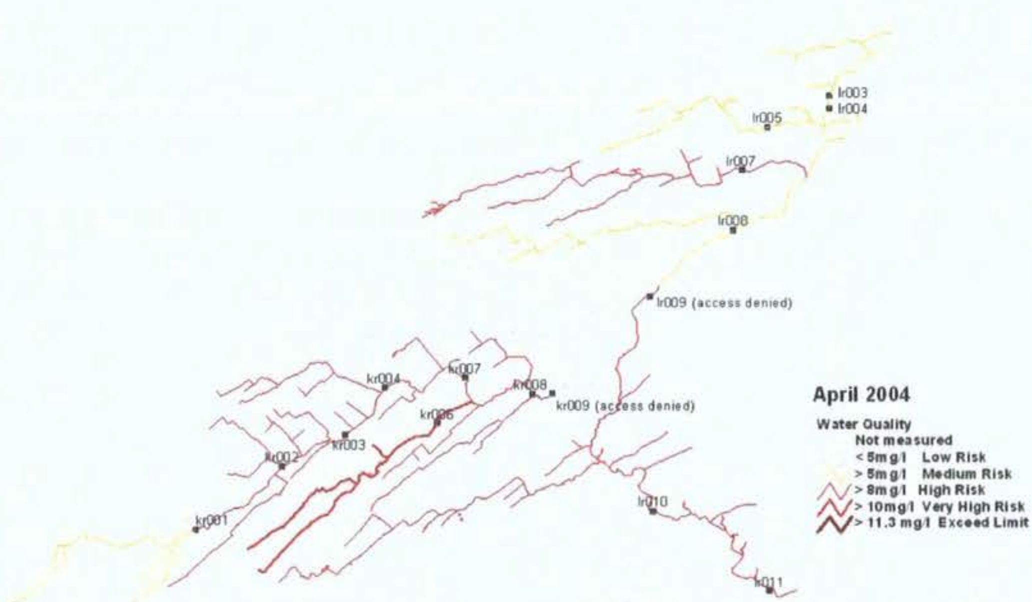


Figure 6.1s NO_3-N concentrations June 2004

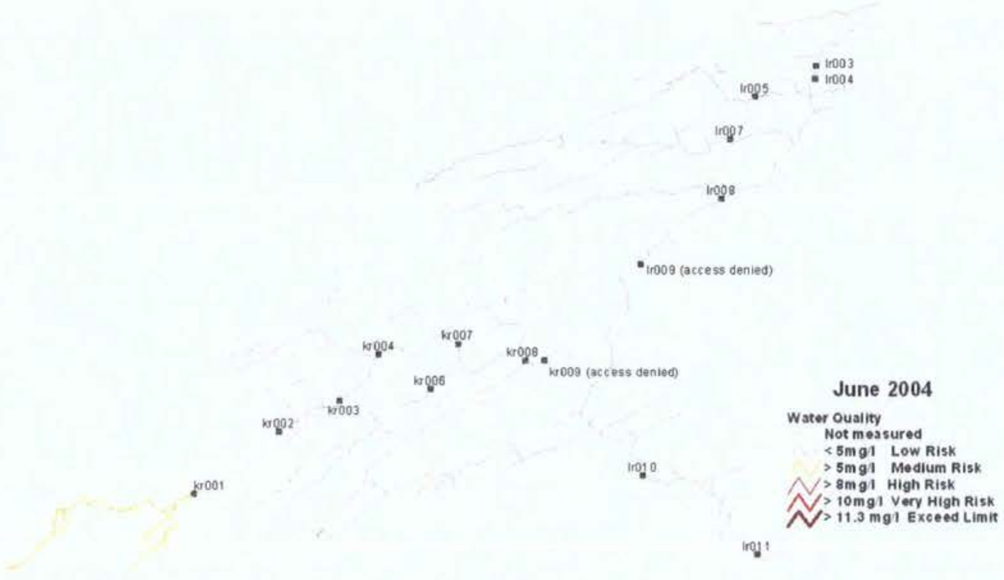
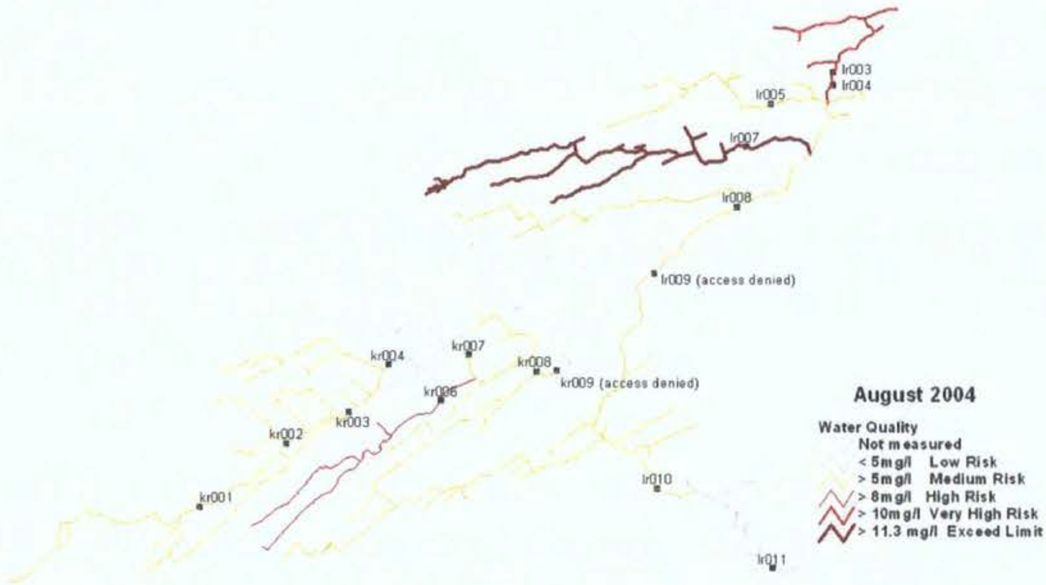


Figure 6.1t NO_3-N concentrations August 2004



INCA Tweed Parameter description for the *.par file	
Row number	**Parameter description for the *.par file**
1	*Title e.g.* Lambden 1994 - 2000
2	*six comma-delimited strings, the short names for each of the six land use groups, e.g.* "Forest","SvegUg","SVegGNF","SVegF","Arable","Urban"
3	*The long name of land use groups e.g.* Forest","SVeg (Ungrazed)","SVeg (Grazed, No Fert)","SVeg (Fert)","Arable","Urban"
4 -11	*Eight rows of data, in six columns (one for each land use group). These are in order:* Surface flow ($m^3 s^{-1}$) Sub-surface flow ($m^3 s^{-1}$) Surface nitrate (mg N l^{-1}) Sub-surface nitrate (mg N l^{-1}) Surface ammonium (mg N l^{-1}) Sub-surface ammonium (mg N l^{-1}) Surface drainage volume (m^3) Sub-surface drainage volume (m^3)
12 - 13	*Time step information, the start date and number of time steps (days) e.g.* 01/01/1994 2557
14 - 38	*Land phase information is in twenty-five rows and six columns (one for each land use group)* Denitrification rate/day Nitrogen fixation (kg N/ha/day) Plant nitrate uptake rate/day Maximum nitrate uptake (kg N/ha/year) Nitrate addition rate (kg N/ha/day) Nitrification rate/day Mineralisation (kg N/ha/day) Immobilisation rate/day Ammonium addition rate (kg N/ha/day) Plant ammonium uptake rate/day Plant growth start day (julian day) Plant growth period (days) Fertiliser addition start day (julian day) Fertiliser addition period (days) Soil Moisture Deficit maximum (mm) Maximum temperature difference (°C) Denitrification temperature threshold (°C) Nitrification temperature threshold (°C) Mineralisation temperature threshold (°C) Immobilisation temperature threshold (°C) Minimum surface flow level ($m^3 s^{-1}$) Minimum sub-surface flow level ($m^3 s^{-1}$) Soil reactive zone time constant (days) Groundwater zone time constant (days) VrMax (depth x porosity) (m)
39-41	*In-stream initial conditions are set for the furthest reach upstream:* flow ($m^3 s^{-1}$), nitrate concentration (mg N l^{-1}), ammonium concentration (mg N l^{-1}).
42	*Number of sub-catchments and reaches,* in this case 10
43 - 52	*Reach descriptors and inputs. Ten rows, one for each reach, with ten columns of data, which are, in order,* Reach name; Length (m); Qa; Qb; Nitrification; Denitrification; Qm^3s^{-1}; NO_3 mg/l; NH_4 mg/l; Input.
53-62	*Sub-catchment descriptors, one row for each sub catchment (in this case 10), with information for* Area (km^2); Percentage of each INCA land use group (six columns); Base Flow Index; dry/wet NO_3/NH_4 deposition (four columns)